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Distribution and Ecology of *Bulinus truncatus* in Khuzestan, Iran*

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The results of a 5-year study on the distribution and ecology of Bulinus truncatus *in Khuzestan, south-western Iran, are described. Live snails were found in 4 foci, namely, the main focus, the upper Karun River, the lower Karkheh River, and the Bala Rud watershed; in addition, dead snails were found in 3 other foci. The patchy distribution of snails was related to the presence of surface waters and to their chemical composition.*

Monthly observations on the population dynamics of the snails and on the role of the snails in the transmission of Schistosoma haematobium *and* S. bovis *were carried out in 14 ponds, 9 canals, 5 swamps, 2 field drains, 1 spring and 1 stream-pool. In standing waters, the peak of snail population could potentially occur in 2 seasons—May–July and November–January—but the main seasons for the transmission of mammalian schistosome cercariae were April–May and October–November. In flowing waters, a higher number of snails might be found in summer in some canals and in winter in another group of canals. Canals were found to be more important sites of transmission of human schistosomes than were village ponds. Transmission took place mainly in hot months when man–water contacts were greatest. Village ponds accessible to livestock were found to be important in the transmission of bovine schistosomiasis. As new irrigation systems have been expanding in this area of Khuzestan, more attention should be paid to flowing waters than to standing waters in future schistosomiasis control programmes.*

Successful schistosomiasis control depends largely on a thorough knowledge of the distribution and ecology of the host snail. In Khuzestan, south-western Iran, where a WHO-assisted Schistosomiasis Control Project is located, *Bulinus truncatus* is the intermediate host of *Schistosoma haematobium* and *S. bovis*. Although specific field studies on the snail host were reported by Gaud et al. (1962) in the endemic area, information about the distribution, population dynamics, ecology and biology of *B. truncatus* was still inadequate. Chu et al. (1967c) studied the biology of the snail in relation to its adaptation to drought in the habitat. In the present paper, our findings during a 5-year period from July 1962 to June 1967 concerning the distribution and seasonal population trends of the snail and its relation to the transmission of *S. haematobium* and *S. bovis* in this endemic area are reported.

DESCRIPTION OF THE ENDEMIC AREA

LOCATION AND NATURAL STREAMS OF KHUZESTAN

Khuzestan is an area of about 157 000 km² and is a continuation of the Mesopotamian plain, bordered in the south by the Persian Gulf, in the west by Iraq and in the north and east by the Zagros mountains (Fig. 1).

Five major rivers draining the south-western slopes of the Zagros Mountains cross Khuzestan.

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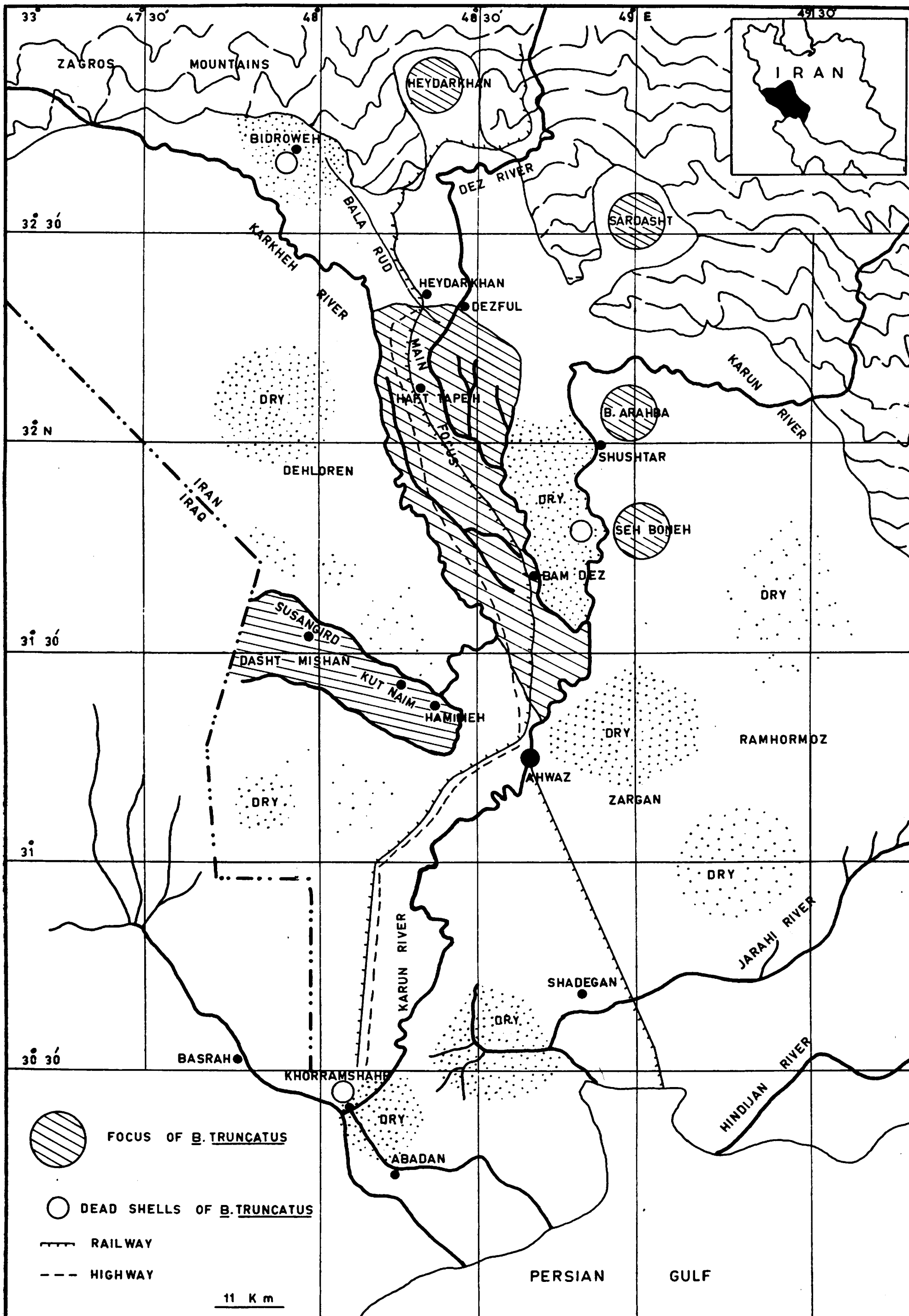
FIG. 1

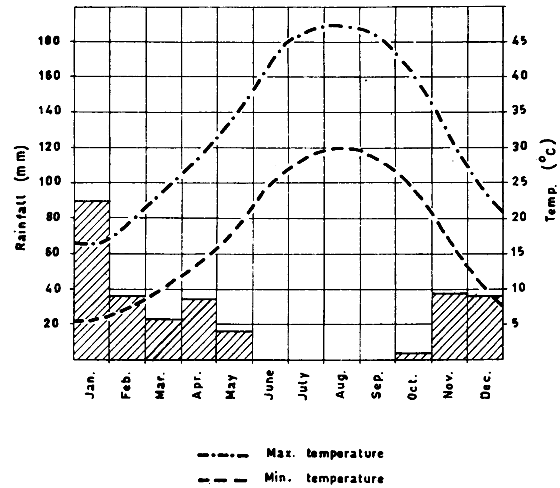
PART OF KHUZESTAN TO SHOW THE MAIN ENDEMIC FOCI OF *BULINUS TRUNCATUS* AND THE MAIN RIVER SYSTEMS



In order from south-east to north-west they are: the Hindijan, the Jarahi, the Karun with its large tributary the Dez, and the Karkheh. The most important of these rivers is the Karun–Dez which has the largest catchment area (54 000 km²) and the greatest volume of water, the average flow being 750 m³/s. The next in size is the Karkheh and between it and the Dez is the Shahur Stream which rises from an underground spring, flows in a channel, part of which is artificial, with one branch discharging into marshes and another into the Dez near the Karun–Dez junction. This river is small but plays an important role in the transmission of schistosomes. The Bala Rud drains about 1000 km² of the lower mountains and joins the Dez downstream of Dezful.

FIG. 2

AVERAGE RAINFALL AND MEAN MAXIMUM AND MINIMUM TEMPERATURES AT DEZFUL [a]



[a] Rainfall average for years 1959–65; average temperature for years 1963–65.

CLIMATE AND TEMPERATURE

Khuzestan is semi-arid and relative humidities are generally low. Summer maximum temperatures are very high, reaching up to 54°C, and frosts occur occasionally in the winter. During the study period between 1962 and 1967, frost occurred only once, from 19 to 23 January 1964.

The annual rainfall ranges from 150 mm to 300 mm; between 350 mm and 550 mm fall on the uplands and considerably more on the exposed slopes of the mountains. The annual snowfall in the high mountains upstream from the site of the Dez Dam is usually equivalent to about 1200 mm of rain with a recorded maximum of 2170 mm. Snow cover is generally limited to areas above 1500 m–2000 m elevation.

Rainfall is limited to the period from November to May and is maximal between December and March. Practically no rain falls during the rest of the year. A large year-to-year variation in precipitation is evident and several relatively dry years in succession have been recorded. Fig. 2 shows the average monthly rainfall during the period 1959–65 and the average monthly maximum and minimum air temperatures during the period 1963–65; the data were collected by the Dez Pilot Irrigation Project at Dezful.

THE SOILS

Most of the soils in the plains are alluvial. Hydromorphic soils are found on the flat lands or in depressions where the excess water lies on the surface during the whole or part of the year as swamp meadow, marsh and salinized marshy soils. Appreciable quantities of gypsum and salt tend to be deposited on the surface, but in well-irrigated areas where soils are frequently washed by fresh water, such deposits are not evident.

FRESHWATER SNAILS IN KHUZESTAN

Snails in the area were collected and taken to the laboratory for identification. The following species have been recognized:

Bulinus truncatus; the species referred to throughout the paper unless otherwise specified.

Lymnaea gedrosiana (Annandale & Prashad); the most common species occurring in the area, thriving in ponds, canals, drains and swamps.

L. truncatula ; found in some swamps and drains.

Gyraulus intermixtus (Mousson) ; found in most ponds together with *L. gedrosiana* and *B. truncatus*.

Melanoides tuberculata (Müller); found in running water and in some swamps.

Melanopsis costata (Ferussac); found in running water and in some swamps.

Melanopsis praemrosa (L.); found in running water and in some swamps.

Melanopsis nodesa (Ferussac); found in running water and in some swamps.

Theodoxus cinctellus (Martens); found in some streams.

Viviparus bengalensis (Lamarck); found in some swamps.

Physa sp.; found in some canals and swamps near Ahwaz.

Bivalves, including *Corbicula* sp. and *Unio* sp.; found in some running waters and swamps.

DISTRIBUTION OF *B. TRUNCATUS* IN KHUZESTAN

The occurrence of *B. truncatus* in the area was first reported by Helmy [1] from the evidence of dead shells collected along the bank of a Hamidieh main irrigation channel and from some channels in the vicinity of the Shahur Dam. Watson (1953) failed to find *B. truncatus* on Abadan Island and in the Ahwaz area. Subsequently, living specimens and snail habitats were discovered by Bijan et al. (1962). Although Gaud et al. (1962) described the distribution of schistosomiasis in Khuzestan province in 7 foci, namely, Bidroweh, Karun focus, Seh Boneh, Zargan, Lower Karkheh area, Khorramshahr and the study area, yet the snail survey was made only in the study area, or northern part, of the main focus.

During 5 years (1962–67) of snail searches covering most bodies of water except rivers, *B. truncatus* was found to be distributed in 4 foci (Fig. 1).

THE MAIN FOCUS

This area is the largest and agriculturally the richest plain and the best-irrigated area in Khuzestan; it is bordered in the north by the slopes north of Dezful and Andimeshk, and in the west and east by the Karkheh and Karun rivers, respectively, and terminates in the south near Ahwaz. For convenience of description, the area has been divided into 3, namely, the northern area, the sugar-cane project area and the southern area.

Northern area

The distribution of snails in this area during the period from 1959 to 1961 was described by Gaud et al. (1962). In the centre (Fig. 3), covering an area of 22 000 ha, is a new irrigation system which was installed between 1962 and 1964; water is drawn only from the Dez River. Previously, there had existed an old system of earth canals and flow of water in them was rapid. The new irrigation system includes main canals, lateral and tertiary canals; some of the canals are cement-lined. The old canals are still used to distribute water to farming land and fruit gardens and as drains to collect water from the field and to discharge it into new large drains which finally empty themselves into the Abjirob Stream and the Dez River. A number of the canals are not in use and some of them dry out from time to time.

During the period from 1963 to 1965, the types of habitat seen were similar to those found by Gaud et al. (1962). They included ponds, some old canals, drains (including marshy drains and canalized drains), swamps (including marshy shallows and rice fields), and springs (pools in dry streams with an underground source of water). From 1965 onwards, an increased number of habitats was found in swamps and in side-pools along new canals and new highways. The excessive use of water in the rice fields may account for the spread of the snails. The flow of water in the old canals was much slower than it had been previously; thus, more canals became infested with *B. truncatus* during 1966. Furthermore, towards the end of 1966, 2 new tertiary canals became infested with snails. In the Lureh area in the east, fed mainly with water from the Lureh Stream which joins the Dez River, snails were found in some springs on the hillsides, and in ponds, swamps, field drains and canals.

Between the lower ends of the new irrigation area and the Lureh area is the Abjirob area where a chain of irrigation canals has existed for some 20 years. The source of water here is the Abjirob Stream, which also collects water from the new irrigation area and discharges through a dam into

[1] Helmy, M. M. (1952) Unpublished WHO working document EM/Bil/3.

FIG. 3

DETAILS OF RIVERS, STREAMS, CANALS AND VILLAGES, ETC., IN THE NORTHERN PART OF THE MAIN FOCUS OF *BULINUS TRUNCATUS* IN KHUZESTAN

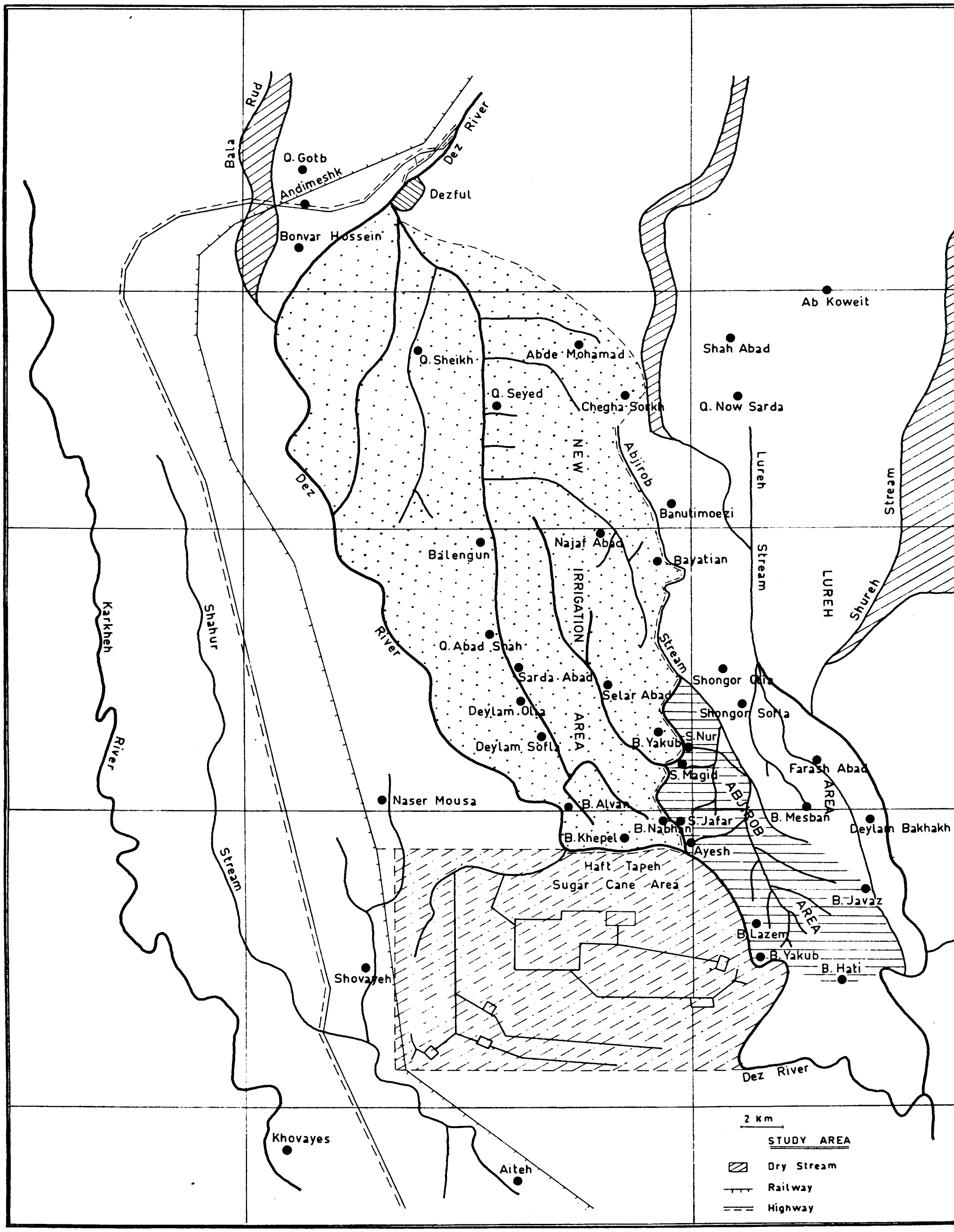


TABLE 1

NUMBER OF SNAIL HABITATS EXISTING FROM 1959 TO 1961 AND FROM 1963 TO 1965 IN THE NORTHERN MAIN FOCUS

Type of habitat	No. of habitats existing during the period 1959–61	Habitats known in 1959–61 that had disappeared in the period 1963–65	No. of habitats existing during the period 1963–65		
			Habitats from 1959 to 1961	New habitats that appeared in period 1963–65	Total
Ponds	32	12	20	29	49
Canals	16	11	5	22	27
Drains including marshy drains and canalized drains	19	8	11	3	14
Swamps including marshy shallow and rice-field	24	9	15	22	37
Springs	2	1	1	2	3
Total	93	41	52	78	130

the Dez River. Snails were found in most canals at their terminal ends and in swamps adjoining the canals.

In the west is an area receiving water from several sources: from the Karkheh River (Harmoshi canals) and from the Dez River; and the Shahur Stream also crosses this area. Snails were found in some swamps, wayside pools and canals. Recently, the Great Dez Project was begun to install a new irrigation system in this area, with water taken from the Dez River.

In order to compare the snail distribution in this area during the period from 1963 to 1965 with that during the earlier study in 1959 to 1961 (Gaud et al., 1962), the definition of a snail habitat as used by Gaud et al. should be modified in 2 instances. First, a continuous body of water, such as a stream, a drain or a canal, where snails were found at several locations, should be considered as a single habitat. Secondly, a site where only a dead shell or many shells were found cannot be considered as a snail habitat since this site might once have been populated by live snails or the shells might have been carried to this site. To satisfy the criteria for comparison we may say that a snail habitat is a body of water in which live snails were found at least once during the period of comparison. Table 1 shows the number and types of snail habitats found during 1959–61 and 1963–65 in the area. The larger number of habitats found during the later period may be, in part, accounted for by the diligence of our searches but the results indicate that disappearance of snails from some habitats and the appearance of snails in some new habitats are common occurrences.

Sugar-cane area (Haft-tapeh)

During the period from 1959 to 1961 when the new irrigation system was not fully in operation for the planting of sugar-cane, Gaud et al. (1962) reported the presence of *B. truncatus* in 3 marshy drains and in 1 other drain. Early in 1965, 13 km of main canals, 30.3 km of secondary canals, and 35.8 km of tertiary canals, in addition to 8 water reservoirs, were in operation. *B. truncatus* were found only in 2 secondary canals and in 4 reservoirs. At the same time in the following year, 5 secondary canals and 4 reservoirs were infested with snails. In June–July 1966, *B. truncatus* were found in 9 reservoirs, and most water-courses, including 4 main canals, 7 secondary canals and 27 tertiary canals. These data show a surprising spread of *B. truncatus* in a new irrigation system.

Southern area

The area is bounded in the north by the sugar-cane area, in the east by the Dez–Karun River, in the west by the Karkheh River and the Ahwaz–Dezful road and in the south it extends to Ahwaz.

The water in this area is derived from the Shahur River which divides into 2 branches (Fig. 3). The upper branch is wide, meandering and overgrown with heavy vegetation; during the dry season (summer and autumn), this branch becomes broken up into several swamps. For this reason, Gaud et al. (1962) reported 11 snail habitats along the length of this stream. During the wet season (winter and spring), water runs and snails are therefore carried to downstream areas. The lower branch of the Shahur River is about 60 km long; it is the main branch and the water flows fast. The area south of the stagnant branch of Shahur River was not surveyed by Gaud et al. Our first survey, carried out in April 1964, revealed the presence of snails in swamps, streams and canals, some of which were still snail-infested at the time of the second survey in June 1966. Our third survey in December 1966 revealed a short canal 2–3 km away from Ahwaz that was infested with *B. truncatus*. The water in this canal was pumped from the Karun River. The fourth survey was carried out in June 1967. In the 2nd survey, 18 snail habitats were found, of which 10 still existed in June 1967. These data indicate the instability of snail habitats in this area.

THE LOWER KARKHEH AREA
(Dashte Mishan; Fig. 1)

This area is bounded in the west by the Iraq frontier, in the north by the dry Dehloren, in the east by Ahwaz and in the south by a desert. A dam was established at Hamidieh where a main irrigation channel feeds water to some canals in the east and south part of this area. The lower Karkheh River divides into 2 branches at Kut Naim. The southern branch was empty of water for the first 7 km; below that point it receives water from the main Hamidieh channel. The northern branch further divides at Susangird and discharges into the marshes adjoining the Iraq border.

In 1952, dead shells of *B. truncatus* were found by Helmy (*op. cit.*) along the bank of a Hamidieh main irrigation channel. In 1959, dead shells were found in canals at Howeizeh by personnel from the Institute of Public Health Research, Teheran. In the same year, Gremliza (1959) found dead shells of *B. truncatus* in the dry Karkheh River bed near Kut Naim and in a swamp 5–7 km south-east of Susangird. Our search for snails was carried out in June 1964 and in December 1965. The area north of the northern branch of the Karkheh River was completely dry during the 2 visits. On the south side, the water was pumped from the river into short irrigation canals along the bank. Although *Lymnaea* flourished in irrigation canals, live *B. truncatus* were found only in a pond at Ghadir, 10–12 km south-east of Susangird and in a drain at Hamidieh in 1964. Dead shells were found at a Shovayeb stream and the entry to the dry Karkheh River bed. In December 1965, no live *B. truncatus* were found and most canals had been dry for a long time. In the large marshes adjoining the Iraq border, only dead *Lymnaea* and live *Viviparus* and *Melanoides* were found in 1964 at high-water level and only *Viviparus* were found in December 1965 at low-water level.

THE UPPER KARUN FOCI
(Fig. 1)

Sardasht area

Snail searches were carried out in the hilly streams in June 1965 and April 1966. Live *B. truncatus* were found at several sites along a stream near Morui. Dead shells were found in 5 other streams. All these streams discharge into the upper Karun River.

Shushtar area

The first snail search was carried out in this area in May 1965. Live *B. truncatus* were found in a large swamp north of Boneh Kazem and a stream near Darb-Vesta. Dead shells were found in a pond at Tabato, in a large swamp near the Karun River between Shalili Bozorq and Bonvar Mohamed Hossein in a large drain near Boneh Arabha and in several dry ponds in 5 other villages. Near Seh Boneh, dead shells were found in several canals. The water in this area is drawn partly from the Karun River and partly from natural streams which finally join the Karun River. The second snail search was carried out in November 1966 and live *B. truncatus* were found in a marshy drain about 3 km long running from Boneh Arahba to Seyed Seyedon.

THE WATERSHED OF THE BALA RUD STREAM
(Heydarkhan)

In January 1963, live *B. truncatus* were found in a stream near Kohnab. Dead shells were found in a dry stream near Boneh Heydarkhan, about

15 km north of Bidroweh. In the following month, live *B. truncatus* were collected in a stream near Kohnab. The water from both these streams discharges into the Bala Rud, which empties into the Dez River at Bounwar Nazer below Andimeshk.

OTHER AREAS

Besides the 4 foci described above, there were 3 foci shown in Fig. 1 where only dead shells were found during the 5 years of survey. In the Bidroweh area, with water from the Bala Rud, live *B. truncatus* appeared in the village 7 or 8 years ago. In the area between the Dez and the Karun rivers, the water is pumped from the Karun River and summer crops are irrigated in a limited area. The presence of dead shells in the short canals might indicate that snails were brought from the Karun River. In the Khorramshar area, dead shells of *B. truncatus* were found in the field channels of a date farm but in the canals *Lymnaea* sp. only were flourishing.

The efforts of our snail searches were extended to (1) Deholoren, the area north of Dashte Mishan and west of Karkheh, (2) the area south-west of Ahwaz including Zargan and Ramhormoz, where the water in streams and swamps contained a high concentration of salt, (3) Shadegan where the dry Jarahi River ends, and (4) the area where the Hindijan River joins the Persian Gulf. On account of the lack of fresh surface water in these areas, no *B. truncatus* could be found and this lack of fresh water may explain the patchy distribution of *B. truncatus* in Khuzestan generally. In a better-irrigated area such as the main focus, snail colonies appear to be more stable than in areas, such as Dashte Mishan and the area between the Karun and the Dez rivers, supplied with water pumped from rivers or in areas, such as the Sardasht area and the watershed of the Bala Rud, watered by natural streams. Even in the better-irrigated main focus, the snail habitats are rather unstable, that is to say, the disappearance of snails from one habitat and the appearance of snails in a new habitat are common events.

With regard to the northern limit of distribution of *B. truncatus*, we found snails in the watershed of the Bala Rud in the north-west, in some dry-stream pools in the north and at Sardasht in the north-east; these areas are located on the southern slopes of the Zagros Mountains. Attempts that were made to search for snails far into the mountain valleys failed because of the inaccessibility of these areas. Heavy snow covers the mountain peaks in winter and in spring water from the melting snow brings down the temperature in the valleys but the temperature of water in the streams never falls below freezing-point. Despite the harsh conditions, we believe that the upper or northern limit of distribution of *Bulinus* may be upstream, deep in the mountains.

Although many rivers flow in the central part of Iran north of the Zagros chain, some of these rivers dry up in the rainless desert and cannot form snail habitats with permanent water. This feature, together with the low temperatures during the winter months, might be the main reason for the absence of *Bulinus* in the central part of Iran.

CHEMICAL COMPOSITION OF NATURAL WATERS IN RELATION TO DISTRIBUTION OF *B. TRUNCATUS*

Subsidiary to our previous work on the distribution of snails in Khuzestan, efforts were made by laboratory experiments and field observations to discover whether the patchy distribution and discontinuous type of snail population in Khuzestan is influenced by the chemical composition of the water. According to Malek (1958), a chemical analysis of water in a schistosomiasis vector habitat should contain the following information: (1) the total salt content; (2) the amount of each cation and anion present; and (3) the ratio of harmful ions to less harmful or beneficial ions. The present report was prepared in accordance with these requirements.

TOTAL DISSOLVED SOLIDS

It is generally assumed that bulinid snails could survive in waters having up to 3000 ppm of total salts (WHO Study Group on the Ecology of the Intermediate Snail Hosts of Bilharziasis, 1957). Nevertheless, the actual range of salt concentration at which snails can perpetuate their species is not yet known. Deschiens (1954) determined experimentally that the maximum tolerated concentration of chlorides as sodium chloride is 2123 ppm for *Bulinus contortus*. Watson (1958) observed that *B. truncatus* could survive in water containing 1500 ppm of dissolved chlorides for the same length of time as controls survived in

Tigris River water and he doubted whether high salinity could be more lethal to the eggs and young snails than to the adults. Saliternik & Wittenberg (1959) found that in water containing 0.25% of sodium chloride, not all adult *B. truncatus* had died after 36 hours' immersion, that the eggs could attain final development, but that young snails died soon after hatching. It might therefore be necessary to know the effects of salt concentration on different developmental stages of the snail before the maximum concentration of salt which this species will tolerate can be determined. Four developmental stages were tested in solutions of sodium chloride of various concentrations in order to determine the net reproduction rate per generation at each concentration. In these tests, the survival and fecundity of the adult snails, the hatching rates of eggs and the rates of development of newly hatched snails up to maturity were measured.

Laboratory experiments

Sodium chloride solutions were prepared from river water in the following concentrations: 0.1 %, 0.2%, 0.3% and 0.4%. The temperature of the solutions was maintained at 21°C–25°C throughout the experiment. Five field-collected specimens of *B. truncatus*, 9 mm long, were kept in 1 litre of solution in a crystallizing dish. A total of 20 snails was used for each concentration. As controls, a further 20 snails were kept under similar conditions in river water only. Water lost by evaporation was replaced daily by adding to the dishes equivalent amounts of distilled water. Numbers of dead snails and the number of eggs laid were recorded daily for a period of 16 days.

Dead snails were removed and replaced by live ones. After 16 days, adult snails were taken out of the dishes and the rate at which eggs hatched was observed for a further 10 days.

To study the development of newly hatched snails to maturity, 50 snails were maintained in each of 0.1%, 0.2%, 0.3% and 0.4% sodium chloride solutions and in river water. After 24 days, if a good number of snails still survived, crowding was avoided by maintaining less than 15 snails in 1 litre of each medium. Those snails surviving to the time when the first egg-masses appeared in each concentration were considered to be mature. The media were renewed every 10 days and distilled water was added each day to the dishes to replace water lost by evaporation. The diurnal water temperatures ranged from 19°C to 23°C. In both experiments, the snails were fed fresh lettuce which was renewed every other day.

The survival and egg-laying rates of the adult snails, the rates of hatching of eggs, and the rates of development to maturity of newly hatched snails in the experimental groups were each compared with those in the control group (Table 2).

The results showed that adult snails were more resistant to increasing salinity than prejuveniles were. In 0.3% sodium chloride solutions which contained 3325 ppm–3420 ppm of total solids, equivalent to 1864 ppm of chlorides, 85% of adult snails could survive for 16 days, close to the maxi-

TABLE 2

NET REPRODUCTIVE RATES OF *B. TRUNCATUS* REARED IN SODIUM CHLORIDE SOLUTIONS OF VARIOUS CONCENTRATIONS

Group	Medium (1 litre)	Total dissolved solids (ppm)	Survival rates of adult snails (1)	Egg-laying rates (2)	Hatching rates of eggs (3)	Development rates of snails from 1 day to maturity (4)	Net reproductive rate [a]
Control	River water	352–380	1.0	1.0	1.0	1.0	1.0
1	River water + 1 g NaCl	1 352–1 437	1.0	0.93	1.0	0.73	0.6 789
2	River water + 2 g NaCl	2 340–2 450	0.95	0.78	1.0	0.20	0.1 482
3	River water + 3 g NaCl	3 325–3 420	0.85	0.50	0.87	0.0	0.0
4	River water + 4 g NaCl	4 310–4 490	0.40	0.30	0.44	0.0	0.0

[a] Product of columns (1), (2), (3) and (4).

mum concentration of chlorides tolerated by *B. contortus* (Deschiens, 1954). However, at this concentration, the egg-laying capacity was reduced to half that of the controls, and no prejuveniles could grow to maturity, although 3 dwarfed snails survived up to 50 days.

With regard to the net reproductive rate per generation (Table 2), the product of 4 physiological phases of the snail is 1.0 for the controls, whereas it is 0.68, 0.15, 0.0 and 0.0 for snails reared in 0.1%, 0.2%, 0.3% and 0.4% solutions, respectively. Under outdoor conditions, monthly egg-incubation periods and growth times for 1-day-old snails to grow to maturity at different seasons were determined and it was estimated that a snail could potentially pass 10 egg-to-egg cycles within a year under local conditions (Chu, unpublished data). Thus, taking a year as the basis for calculation, then in 0.1% sodium chloride solutions, the net reproductive rate per year would be 47.3 times less than the controls; in 0.2% solutions, it would be about 1.95×10^8 times less than the controls. Thus, a habitat with water having a salt content of water about 1300 ppm may be inhabited by snails but at a low population density; but when the salt content rises to over 2000 ppm, the snails may disappear. Such habitats, swamps for example, are not uncommon in areas irrigated with a minimum amount of water where drying out results in a rising salt content.

Field observations

Water samples were taken from various parts of Khuzestan and chemical analyses were carried out by courtesy of the Chemical Analysis Laboratory of the Khuzestan Water and Power Authority, at Dezful. Table 3 shows the electrical conductivity, total dissolved solids and hydrogen-ion concentration of water in relation to the presence or absence of *B. truncatus* in the habitat.

The river waters of Khuzestan contain 340 ppm–540 ppm of total dissolved solids. However, Khuzestan can be divided into three distinct areas with respect to the surface water supply.

Well-irrigated areas. Three agricultural plots, including the new irrigation area, the sugar-cane area, and the Abjirob area, were well-irrigated, with the two former being irrigated from the Dez River, and the latter by the Abjirob. To judge from the chemical composition of water in any of the habitats and from the distribution of snails, the water in these areas was favourable to *B. truncatus*. However, there were several ponds, canals and swamps containing water with a favourable chemical composition but no *B. truncatus,* only *Lymnaea gedrosiana*. This shows that the chemical composition of the water alone can not be used to predict the presence or absence of *B. truncatus*.

Less-irrigated areas. Three areas in the main focus, including the Lureh area, the area between the Dez River and the Karkheh River and the southern area, were less irrigated in comparison with other foci. There were a number of swamps in the two former areas that were subject to severe water fluctuation. In a swamp located in the Lureh area, recession of the water, resulting in an increase of salt content from 1100 ppm to 2230 ppm, is a limiting factor for the existence of *B. truncatus*. In this swamp, live snails were collected only once when the water level was high. These snails had apparently been carried down from an incoming snail-infested canal and had bred at a limited rate until the water level dropped.

In the southern area, the Shahur Stream irrigated a limited area in the west only and water was pumped from the Dez–Karun River to a much smaller area near the bank. A huge swamp was located in the centre of the area and a good number of smaller swamps on all sides. In some of these swamps, snails were found occasionally in very low densities. In a very large, isolated body of water (Dead Dez) at Bam Dez where the old Dez River ran, the water contained 8876 ppm of salt, but dead shells of *B. truncatus* indicating that snails once survived there.

For agricultural purposes, primitive drainage existed in some of the swamps and frequent flows of fresh water had diluted the salt contained in the water and the soil, so that the water here would be favourable for *B. truncatus*. But in most swamps in the less-irrigated areas, little or no drainage existed and these swamps expanded in size as the water level rose or receded to central depressions as the water level fell. Therefore, at high water levels, the chemical composition of water was favourable for the survival of *B. truncatus*, but at low water levels, the salt content might rise beyond the maximum tolerance limit of the snails so that the snail population might come close to eradication and, especially in hot summers, it seems likely that the osmo-regulatory systems of

TABLE 3

ELECTRICAL CONDUCTIVITY, TOTAL DISSOLVED SOLIDS AND HYDROGEN-ION CONCENTRATION OF WATER FROM KHUZESTAN

Area	Sampling site	Water source (river or stream)	Electrical conductivity (× 10^{-6} mho)	Total solids (ppm)	pH	*B. truncatus* present or absent
			Well-irrigated			
New irrigation area	Entrance of the Dez	Dez	375	340	7.7	No survey
	Bayatian Pond	Dez	536	360	7.6	Present
	Qaleh Seyed Pond [a]	Dez	1 000	680	7.9	Present
	Deylam Sofla drain	Dez	784	484	8.0	Present
	Shagheri drain	Dez	700	422	7.9	Present
Abjirob	Stream	Abjirob	447	370	7.6	No survey
	A canal	Abjirob	687	630	7.8	Present
Junction of the Abjirob and the Dez		Dez	635	450	7.7	No survey
			Less-irrigated			
Lureh	Canal 1	Lureh	1 894	940	7.9	Present
	Canal 2	Lureh	1 793	960	7.6	Present
	Swamp 1	Lureh	2 130	1 100	7.7	Present
	Swamp 1 [a]	Lureh	3 524	2 230	7.6	Dead shells
	Swamp 2 [a]	Lureh	3 433	2 000	7.4	Absent
Area between the Dez and Karkheh rivers	Canal 1	Karkheh	970	626	7.7	Present
	Canal 2	Karkheh	940	648	7.8	Present
Southern area of the main focus	Stream	Shahur	765	540	8.0	Present
	Dead Dez at Bam Dez	Isolated	13 500	8 876	7.2	Dead shells
Sardasht	Watershed	Karun	850	514	7.9	Present
Shushtar	Swamp	Karun	1 150	796	7.3	Present
Khorramshahr	Canal	Karun	1 480	920	7.6	Absent
Lower Kharkheh	Upper stream	Karkheh	602	450	7.6	No survey
	Downstream	Karkheh	622	490	7.8	No survey
	Terminal swamp	Karkheh	1 350	968	—	Absent
	Terminal swamp [a]	Karkheh	4 000	2 452	7.6	Absent
Heydarkhan	Watershed	Bala Rud	532	360	7.6	Present
	Downstream	Bala Rud	535	384	7.7	Dead shells
			Non-irrigated area			
Shadegan	Swamp	Jarahi (dry)	5 000	3 200	7.7	Absent

[a] At low water level.

the snails would not be able to adjust to the high temperature and high salt content of the water. Therefore, *B. truncatus* might be found occasionally in very low densities in these swamps. This factor, together with the drying out of habitats, appeared to be the cause of the discontinuous type of snail population in swamps.

In the Lower Karkheh (Dashte Mishan) area, except for the main irrigation canal and the river, irrigation canals were very short and dry in autumn

TABLE 4
IONIC CONTENT OF REPRESENTATIVE SAMPLES OF WATER FROM KHUZESTAN

Water source	Ions (ppm)								
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{2-}
Entrance of the Dez into the new irrigation area	66.0	6.1	35.2	1.2	15.0	82.3	88.8	44.4	12.4
Dead Dez at Bam Dez	576.0	124.0	2 073.9	12.5	0	112.8	633.1	4 011.5	12.4
Susangird swamp:									
High water level	96.0	24.2	140.0	3.9	0	244.0	139.0	198.0	6.2
Low water level	240.0	108.2	409.9	5.5	0	329.4	676.3	701.1	2.5
Sardasht Stream	51.2	27.2	93.8	6.2	0	317.2	29.8	110.0	6.8
Shushtar Swamp	56.8	17.0	177.1	4.3	0	158.6	81.6	266.2	2.5
Khorramshahr Canal	90.4	39.9	145.8	3.5	0	207.4	190.6	250.3	2.5
Shadegan Swamp	440.0	82.7	460.0	7.8	0	146.4	1 211.0	781.0	4.3

and winter. In the swamps adjoining the Iraq border, the salt content of the water was 968 ppm at high water levels, but rose to 2452 ppm when water levels were low, thus amounting to a limiting factor for snail colonization.

The canals around the city of Khorramshahr were subject to tidal flow. Water from a canal was analysed in December 1965 and was found to contain 960 ppm of total dissolved solids. No *B. truncatus* were found but *Lymnaea gedrosiana* were flourishing. However, dead shells of *B. truncatus* were scattered in date-palm ditches which were irrigated by these canals. This observation indicates that the salinity of canal water may not be so high as to prevent the breeding and development of *B. truncatus* but there are probably other reasons that would account for the absence of *B. truncatus* and the presence of *L. gedrosiana* in these canals.

Areas with no irrigation systems. In Zargan, Ranhormoz, Shadegan and Dehloren, no irrigation systems existed and the surface waters in the first 2 areas contained so much salt that table salt was at one time extracted commercially. In Shadegan, water from a swamp contained 3200 ppm total solids and would be unfavourable for the survival of *B. truncatus*. In Dehloren, a deficiency of surface water made this area unfavourable for snails.

IONS PRESENT IN NATURAL WATERS

The cations and anions of the representative water samples from various areas of Khuzestan are presented in Table 4.

Calcium

The amount of calcium is taken as a measure of the hardness of the water. Based on the calcium content, Boycott (1936) classified water with respect to the mollusc fauna into 4 categories. As Table 4 shows, the waters in Khuzestan contained from 51.2 ppm to 576 ppm of calcium and belonged to the very hard type.

Magnesium

The magnesium content of water in Khuzestan was low in comparison with the calcium content. The Ca/Mg ratio was from 1.88 in the Sardasht water to 10.98 in the Dez River water, both waters being favourable for *B. truncatus*.

Sodium

Sodium occurs in the form of chloride, sulfate and carbonate. In our water samples, the sodium content ranged from 35.2 ppm in the Dez River water to 2073.9 ppm in the Dead Dez water where dead shells of *B. truncatus* were collected. It is maintained by Malek (1958) that water with a high concentration of sodium ions compared with other cations, especially calcium, is not favourable for snails. The Na/Ca ratio of the water was 1.83 and 3.12 in the Sardasht Stream and Shushtar Swamp, respectively; *B. truncatus* was present in both. On the other hand, the ratios were 1.46–1.67, 1.61 and 1.05 in the Susangird Swamp, Khorramshahr Canal, and the Shadegan Swamp, respectively, but no *B. truncatus* were present. In the laboratory, Frank (1963) demonstrated in waters containing 4 ppm–18 ppm of calcium carbonate that fecundity of *Biomphalaria* was depressed by an increase in the Na/Ca ratio, but the results obtained in our experiments were not in agreement in this respect. We used river water which had a Na/Ca ratio of 0.55 and 0.1 % sodium chloride solutions with a Na/Ca ratio of 6.5. The fecundity of snails in 0.1 % sodium chloride solution was reduced to only 7% of that of snails reared in river water. Possibly the difference may be due to the high calcium content of the water.

Bicarbonate

Bicarbonate occurs in the form of calcium, magnesium, sodium and potassium salts, and is usually taken as a measure of the alkalinity and the temporary hardness of water. In our water samples, the bicarbonate content ranged from 82.3 ppm in the Dez River water to 329.4 ppm in the water of the Susangird Swamp. Because of the high content of this anion, the pH of the water in Khuzestan was adequately buffered with a range from 7.2 to 8.0.

Sulfate

The sulfate content of the Khuzestan waters was high, with a range from 29.8 ppm in the Sardasht Stream to 1211 ppm in the Shadegan Swamp. *B. truncatus* were found in waters that have a low sulfate content, such as the Sardasht Stream (29.8 ppm), the Shushtar Swamp (81.6 ppm) and the area irrigated by the Dez River (88.8 ppm), but not in waters having a higher sulfate content, such as the Khorramshahr Canal (190.6 ppm), Susangird Swamp (139.0–676.3), the Dead Dez (633.1 ppm) and the Shadegan Swamp (1211.0 ppm). According to Deschiens (1954), the maximum tolerated concentration of sulfate as Na_2SO_4 is 1350 ppm for *B. contortus*. Thus, the waters in Khuzestan might be within the tolerance limits of sulfate ions for *B. truncatus*.

Chlorides

The chloride content ranged from 44.4 ppm to 4011.5 ppm in our water samples. In Puerto Rico, Harry & Aldrich (1958) found evidence suggesting that, when the ions are expressed in equivalents per million, a ratio of weak acids (bicarbonate and carbonate) to strong acids (chlorides and sulfates) of more than 3 was unfavourable for *Australorbis*. Schutte & Frank (1964) found that neither *Bulinus* nor *Biomphalaria* seemed to be limited in this way in South Africa. In the waters of Khuzestan, because of the high content of strong acids, the ratios were lower, with a range between 0.28 in water of the Shushtar Swamp and 1.41 in water of the Sardasht Stream; both habitats were snail-infested.

FIELD OBSERVATIONS ON SEASONAL POPULATION TRENDS OF *B. TRUNCATUS* AND ITS RELATION TO TRANSMISSION OF *SCHISTOSOMA HAEMATOBIUM* AND *S. BOVIS*

STUDY AREA

The area of our study lies mainly south of Andimeshk–Dezful, north of a stagnant branch of the Shahur Stream; it is bordered in the west by the Karkheh River and in the east by the Shureh Stream, a branch of the Lureh Stream. The area occupies over 1000 km². The main water-course in this area is the Dez River which collects water from the west, east of the Bala Rud, the Abjirob and the Lureh. Moreover, the Shahur Stream is located in the west and a canal from the Karkheh also crosses the area between the Shahur Stream and the Dez River.

MATERIALS AND METHODS

At the beginning of the present study in September 1962, 20 habitats which were previously infested by *B. truncatus* were selected; 10 habitats (group A) were used to study monthly population trends and the other 10 (group B) were used to study natural schistosome infections of snails. However, it was found that only 6 habitats in group A and 9 in group B were actually infested with snails. Later, when new habitats had been found, some of these were included in the studies. At the beginning of 1964, some canals with running water were selected to study population trends and natural infections of snails (group C).

In group A, snails and egg-masses were collected monthly in dip-nets at marked sites from 5 ponds and a pond-like swamp, using the method of Olivier & Schneidermann (1956). In a large swamp, collections were made by passing nets at 1-metre intervals along the longitudinal and lateral mid-lines. In a spring, snails and egg-masses were counted on the undersurface of 100 submerged stones, 10 cm–20cm long. The snails were measured and those less than 6 mm long were considered as young. The number of eggs in each egg-mass was counted. The snails and egg-masses were returned to the habitats immediately after the data were recorded.

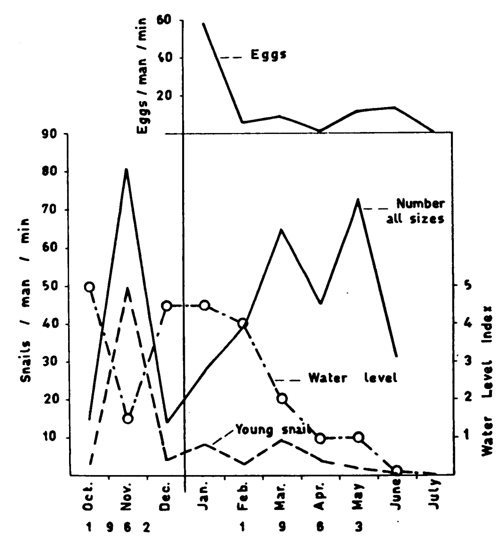
In addition, water levels of the habitats were recorded on each occasion, and recorded numerically. The highest water level was designated " 5 " and " 0 " was recorded when the habitat was nearly dry or dry.

In group B, snails were collected monthly at fixed sites at each habitat. In an attempt to detect seasonal fluctuations of snail populations as well as cercarial infection rates, snails were collected in as uniform a manner as possible by using the method of Olivier & Schneidermann (1956). The habitats included 8 ponds, 3 swamps and a stream-pool. In the laboratory, the snails were measured and individually crushed and examined for schistosome infections. Beginning in early 1963, a local rodent, *Tatera indica,* or white mice, were exposed to the cercariae of any mammalian schistosome shed by at least 2 individual snails from a habitat. Occasionally, rodents were directly immersed in the habitat. The exposed rodents were dissected 3 months later to identify the species of schistosome from the morphology of uterine eggs and eggs deposited in the liver tissues of the hosts.

In group C, 30 nets were each passed at 1-metre intervals at 10 sites along each canal during our regular survey, but the majority of snails were collected at 1 site, usually the terminal end. In the laboratory, snails were individually crushed to determine if schistosome infections were present. When more than 1 infected snail was obtained from any canal at one time, an identification of the schistosome was made. Observations were carried out in 2 canals in the sugar-cane area, 5 canals in the Abjirob canal, 1 old canal in the new irrigation

FIG. 4

MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS AND FLUCTUATIONS OF WATER LEVEL IN A BAYATIAN POND



project area, 1 canal and 1 field drain in the Lureh area and 1 field drain in the western area.

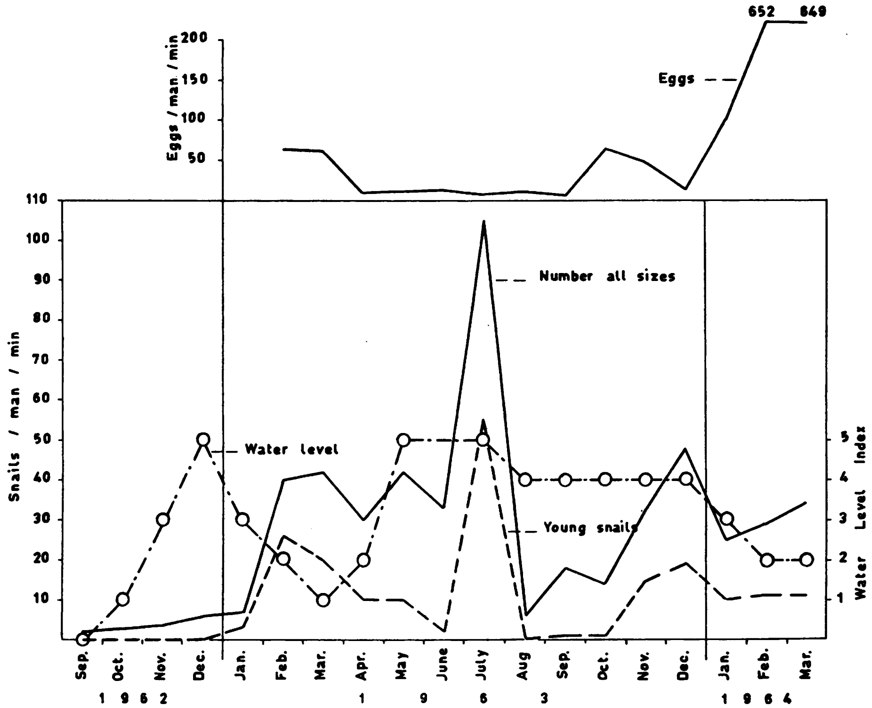
RESULTS

Population dynamics in standing waters

Bayatian Pond. This habitat was a terminal pond, located near the village, filled with water from a leaking canal. It covered a surface of 300 m^2; the water was 1 metre deep at high water level and the total depth of the pond was 2 metres from ground level. Dense vegetation, mainly *Panicum* and scarce *Polygonum,* grew on the edges. The data from monthly observations from October 1962 to July 1963 are shown in Fig. 4. The first peak of snail population was observed in November 1962 at a low water level; over 60% of the snails were young ones. In the following 2 months, the snail density remained low. With intensive breeding in January 1963, high catches of snails were made in March and May, respectively. However, the proportion of young snails in March was rather low in comparison with the number collected in November. After progressive regression of the water in the spring of 1963, the habitat became dry in early July. The pond refilled in early October 1963 but since then, the pond had been dry at all times.

FIG. 5

MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS AND FLUCTUATIONS OF WATER LEVEL IN A NAJAF ABAD POND

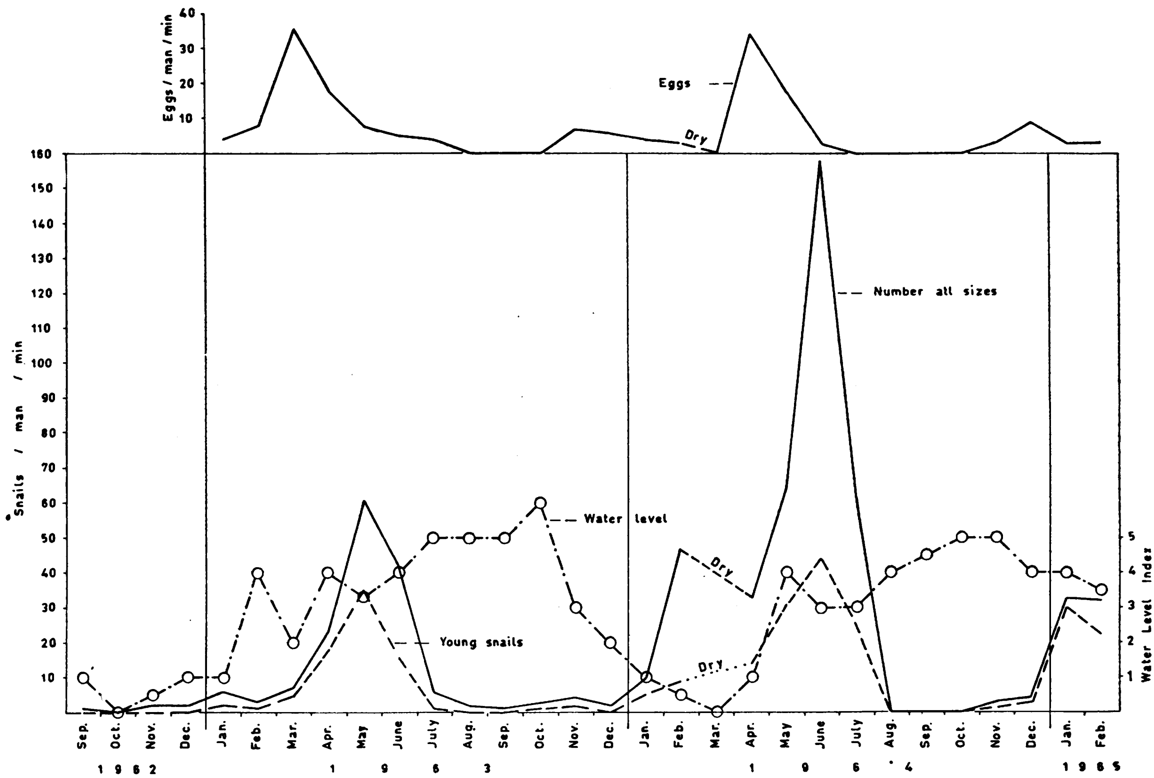


Najaf Abad Pond. This was a terminal pond located inside the village and measured about 40 metres long by 20 metres wide; the pond was 2 metres deep from ground level and contained 1 metre of water when moderately filled. The habitat became infested by snails not long before our observations started. There was no visible vegetation, either submerged or emerged, until June 1963, when *Polygonum* began to grow on the edges. The bottom of the pond was silty and contained a large quantity of organic matter. Water was collected from adjoining gardens and the pond was almost dry in September 1962. The data from monthly observations from September 1962 to March 1964 are shown in Fig. 5. The pond was finally filled with earth in early April 1964. Low levels of water prevailed in early spring and high levels in summer and autumn. The first intensive period of breeding of snails in 1963 was in February–March; 95% of the egg-masses were collected on the shells of *Lymnaea gedrosiana* and 5% on the shells of their own species. A second period of intensive breeding occurred in October–November and all the egg-masses were found on the leaves or stems of *Polygonum*. High snail densities were maintained in February, March and May and a major peak was reached in July. After a population depression in August and September, the snail population built up to a secondary peak in December. The prolonged breeding activity and high density of snails in this pond might have been due to the high degree of water conservation in a deep pond which allowed only mild fluctuations of water level, and to the abundant organic matter at the bottom of the pond.

Balengun Pond. This was a terminal pond located against a garden wall and receiving water from a garden drain. It was 70 metres long by 30 metres wide and 1 metre deep. The data from monthly observations from September 1962 to February 1965 are shown in Fig. 6. The pond was dry in October 1962 and in March 1964. Low water levels prevailed for several months prior to

FIG. 6

MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS AND FLUCTUATIONS OF WATER LEVEL IN A BALENGUN POND

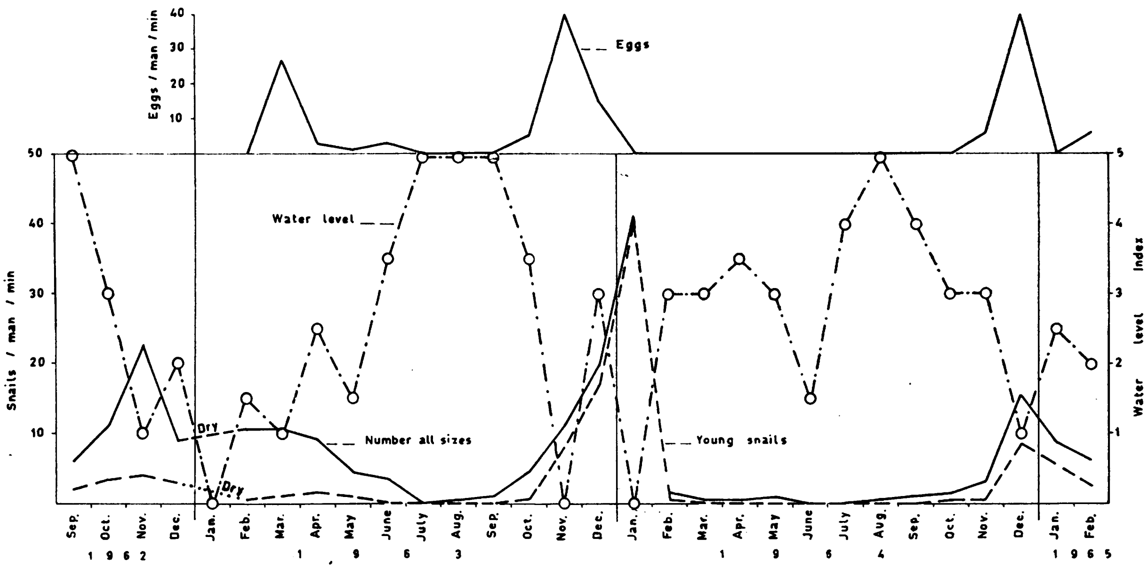


dry seasons, while high water levels occurred in warm months. The major breeding of snails occurred in March 1963 and in April 1964 and each breeding period was followed by a major population peak 2 months later. The pond froze on 19–23 January 1964 but the snail density was not reduced in this pond or in the Najaf Abad Pond. A large number of snails was collected in February 1964; this might be accounted for by the low water level at the time, a reduced number of nets being passed along the edges of the pond.

Qaleh Sheikh Pond. This was a terminal pond located against a garden wall; it measured about 100 metres long by 5 metres wide and was 0.4 metre deep at high water level. The water collected from a leaking garden drain. The vegetation was moderate and mostly on the edges, with some *Typha* growing in the centre. The data from monthly observations from September 1962 to February 1965 are shown in Fig. 7. The first peak of snail population occurred in November 1962 when snails were collected at a low water level. The snails survived a dry season in January 1963 and reappeared in February with the return of water. Intensive breeding took place in March, but the snail density decreased progressively. After the high summer temperatures, the snail population gradually increased, with intensive breeding occurring in November and a peak of snail population in early January 1964. The population then consisted predominantly of young snails. However, the freezing temperatures in the second half of the month killed the majority of snails in this shallow habitat. In spite of the high water levels that prevailed throughout most of 1964, the snails did not increase in number until December. Meanwhile intensive breeding was also observed but the snail densities fell in the following 2 months.

FIG. 7

MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS AND FLUCTUATIONS IN WATER LEVEL IN A QALEH SHEIKH POND



The Bonvar Hossein ponds. These were a chain of 3 ponds, located 100 metres from the village, with water draining in from the adjoining cultivated field and a small canal. The ponds were similar in size, each about 200 m² in surface area. One pond contained *Typha,* and another did not, but the central one had some scattered *Typha*; the edges of all the ponds were covered with emerged plants. The snail collections were made in the 2 outer ponds. It was always found that the snail density was higher in the pond without *Typha* than in the one with *Typha.* The data from monthly observations from January 1964 to January 1965 are shown in Fig. 8. During the observation period, the first peak of breeding occurred in May 1964 and was followed by a peak of snail population in July. The second breeding peak occurred in November and was followed by a population peak in January 1965. Young snails were in the majority in both population peaks.

Qaleh Abad Shah pond-like swamp. This small pear-like depression was located 150 metres away from the village and measured about 200 metres long by 70 metres wide; the water came from a leaking canal and from the field. Scattered plants grew everywhere with *Potamogeton* in the centre

FIG. 8

MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS AND FLUCTUATIONS OF WATER LEVELS IN BONVAR HOSSEIN PONDS

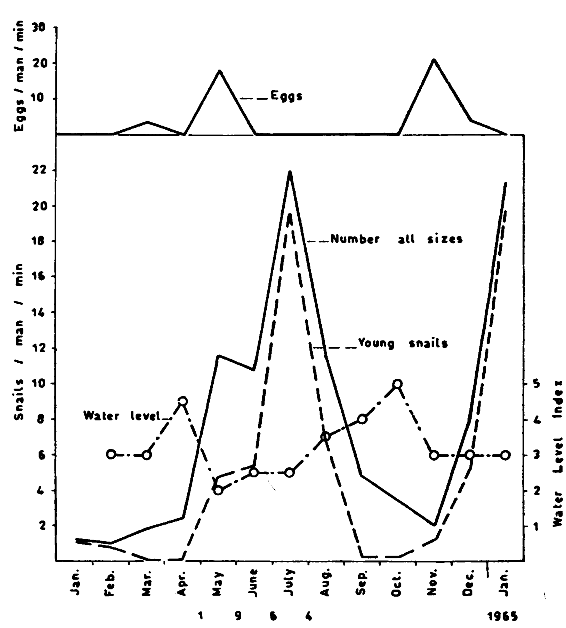
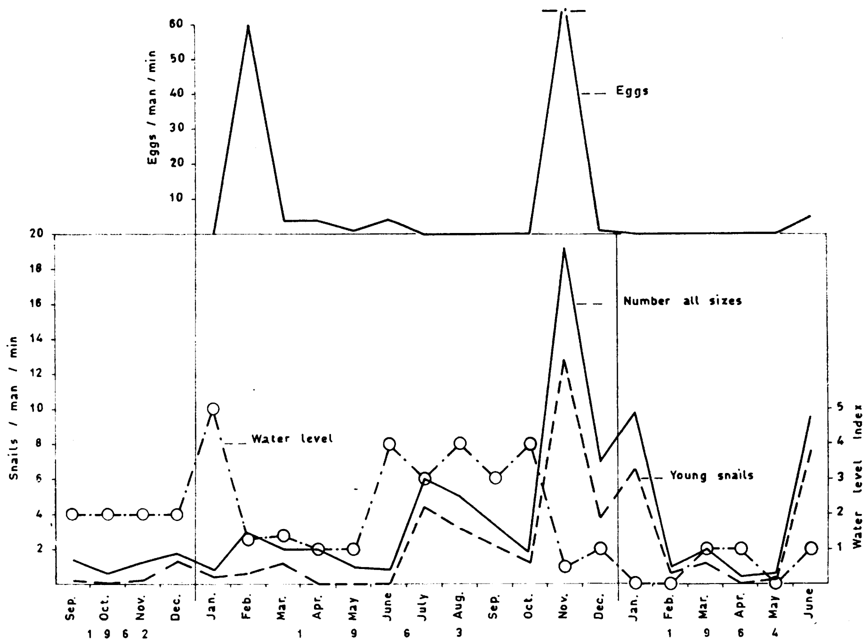


FIG. 9

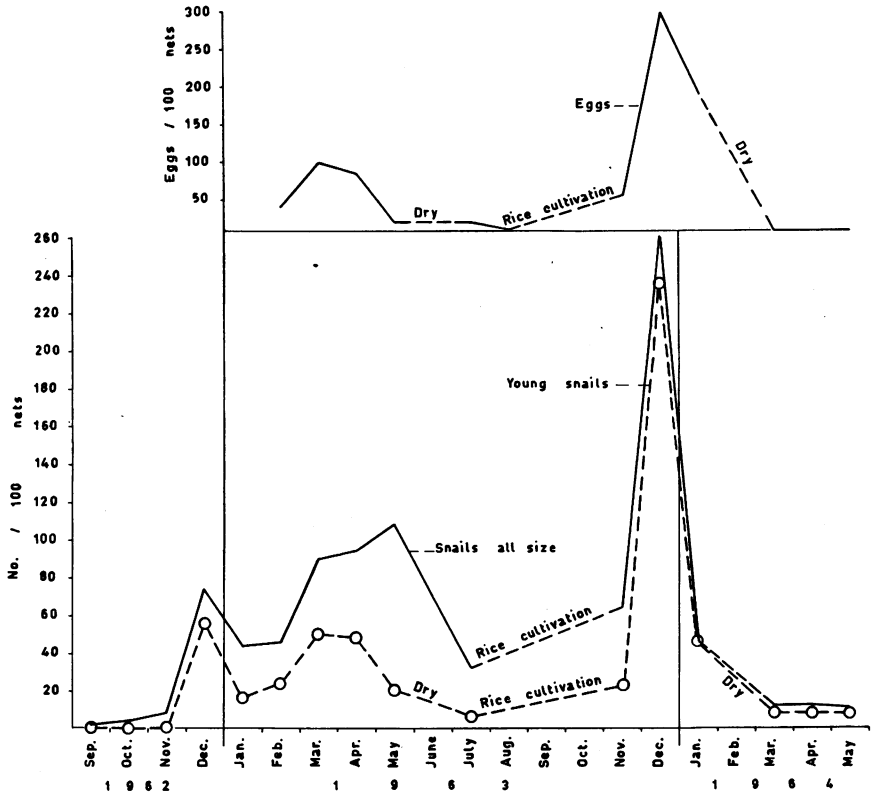
MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS AND FLUCTUATIONS OF WATER LEVEL IN A SMALL QALEH ABAD SHAH SWAMP



and *Typha* at one end. At high water levels, the adjoining field was submerged. The daily fluctuation in water level was severe. The habitat was shallow, about 40 cm deep in the centre at a moderate water level; excess water discharged into a drain. The data from monthly observations from September 1962 to June 1964 are shown in Fig. 9. High water levels were observed in January and the summer months of 1963; low water levels were observed in spring, late autumn of 1963 and first 6 months of 1964. The main breeding season occurred in February 1963 but snail densities did not increase in the following months, until July when a peak developed. A major peak was found in November in the same year but no egg-masses were recovered during the 4 previous months. The apparent absence of breeding activity might have been due to the fact that the snails in this habitat were concentrated in the centre of the pond under the *Potamogeton,* whereas our collections were made only at the edges. In November 1963 when a peak in the snail population was observed, a large quantity of egg-masses was collected; however, the snail densities decreased in the following months. The habitat was frozen from 19 to 23 January 1964. In June 1964, a population peak occurred, but there was no breeding activity in the following months. The habitat became dry in summer of 1964 and no live snails were found until April 1965.

Khovayes Swamp. This habitat, which was located 150 metres away from the village and measured about 200 metres long by 70 metres wide, was filled with water from a leaking canal and from the field. Scattered plants grew everywhere, with *Potamogeton* dominant in the centre. The swamp was dry in June 1963 but was soon used for rice-cultivation; it again became dry in February and in the summer of 1964. The data from monthly observations from September 1962 to May 1964 are shown in Fig. 10. Intensive breeding occurred in March–April 1963 and a minor population peak was reached in May. The habitat was dry in June but was used for rice-cultivation in August–October. A major peak was observed in December and at the same time there was intensive breeding. The young snails repre-

FIG. 10
MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS IN A KHOVAYES SWAMP



sented a higher proportion of the peak population in December than in May. In spite of the abundant eggs found in December, the snail population did not increase in the following month; in fact there was a tremendous decrease. The habitat was entirely frozen from 19 to 23 January 1964 and this was followed by a drought in February. The few surviving snails could not increase their numbers before summer and, after a summer drought, no live snails were found until November 1965.

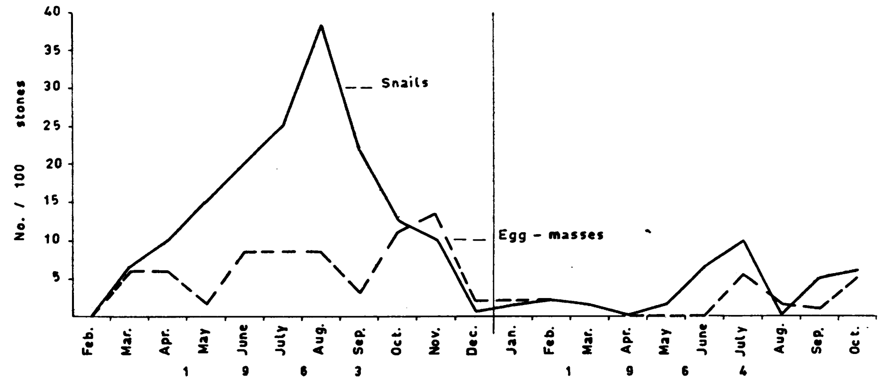
Ab Koweit Spring. This spring was located in a hilly stream which was dry at all times except on days of flooding. The water level of this habitat was high in winter and spring but low in summer and autumn. There was no visible vegetation at any time during the year. The bottom of the spring was stony. The results of monthly observations from February 1963 to October 1964 are presented in Fig. 11. A peak of snail population was reached in August 1963 and in July 1964, The number of egg-masses collected was high in June–August and November of 1963, and in July and October of 1964 in comparison with other months of those years. Altogether, the results show that *B. truncatus* breeds all year round and that there is a yearly variation of snail density in a habitat.

Natural schistosome infections in standing waters

The Shahabad ponds. The village had a population of 667 persons, of whom 33% were infected with *S. haematobium*. During the study period, 3 shallow ponds (borrow-pits) were infested with *B. truncatus*. Ponds A and B were located close to the village. Only submerged plants grew in pond A, but *Typha* and other plants were flourishing in ponds B. The former received excess

FIG. 11

MONTHLY DENSITIES OF *BULINUS TRUNCATUS* ADULTS AND EGGS IN AN AB KOWEIT SPRING



water from the field and the latter received water from pond A and also from a garden drain. Pond C was 300 metres away from the village and received water from a garden drain. In size it was about 40 metres long by 30 metres wide and contained a moderate growth of *Typha*, *Polygonum* and *Panicum*.

The data from monthly observations on pond C from October 1962 to May 1964 are given in Table 5. Autopsies of rodents that were exposed to cercariae from the crushed snails or directly immersed in the pond revealed that both *S. haematobium* and *S. bovis* were present. The peaks of snail population were reached in Novem-

TABLE 5

NUMBERS OF *B. TRUNCATUS* COLLECTED MONTHLY AND NUMBERS INFECTED WITH SCHISTOSOMES FROM 3 VILLAGE PONDS IN KHUZESTAN

Month	Shahabad Pond C [a]			Chegha-Sorkh Pond [a]			Shongor-Sofla Pond [a]		
	1962	1963	1964	1962	1963	1964	1962	1963	1964
Jan.		2/49	0/8		4/181	—		0	0
Feb.		2/93	0/29		12/720	0/165		0/1	0/1
March		0/70	0/36		46/456	0/61		0/3	Dry
April		1/122	0/2		6/337	4/360		—	0
May		1/164	0/0		13/248	57/2 301		0/149	0
June		0/37	Filled with earth		20/3 022	6/462		0/210	0/24
July		0/111			6/3 244	0/488		Dry	0
Aug.		0/52			15/1 328	0/370		0/85	0/1
Sept.		0/30		0/57	3/269	0/74	0/11	2/175	0/60
Oct.	0/27	0/3		51/125	3/239	20/1 525	6/237	5/1 039	5/79
Nov.	1/188	0/3		11/745	6/314	20/9 235	1/156	3/383	0/372
Dec.	0/44	0/2		1/88	4/402	0/1 493	Chem.[b]	Chem.[b]	0/37

[a] Numerators = number of snails with mammalian schistosome infections; denominators = total number of snails collected.
[b] Molluscicide was applied.

ber 1962 and in May 1963. This pond, together with the other 2 habitats, were cleaned out with bulldozers in May 1964.

In pond B, 202 adult snails were collected in August 1962, 81 of which were infected with schistosomes. The habitat was dry in the 2 following months; water refilled the pond in late October and snail collecting resumed in November. Of the 157 snails collected in November, 18 harboured schistosome infections. In December 1962, 18 snails were collected but none were positive for schistosomes. Subsequently, the habitat was dry until it was filled with earth in May 1964.

Pond A came to our attention in January 1964, since previously it had been frequently dry. The numbers of snails collected in this pond from January 1964 to May 1964 were 684, 348, 132, 160 and 158 for 5 consecutives months. The numbers of snails with cercarial infections were 13, 1, 0, 1, and 3, respectively. Autopsies of rodents exposed to the cercariae revealed the presence of *S. bovis* only.

Chegha-Shorkh Pond. The village had a population of 232 persons and 1% were infected with *S. haematobium*. A large, deep pond was located in the village and was shaded by trees on all sides; water plants grew on the edges and *Typha* was scattered on the shallow side of the pond. Water drained into the pond from a garden drain or occasionally from a leaking canal or from the field. The data from monthly observations from September 1962 to December 1964 are given in Table 5. It was found that cercariae from the crushed snails when used to infect rodents developed into *S. bovis* only. The infected snails were found in all months of 1963 but only in the spring and autumn of 1964. The peak of snail population occurred in June–July in 1963, but in May and November in 1964.

Shongor-Sofla Pond. The village had a population of 135 persons, 63% of whom were infected with *S. haematobium*. The pond was a side-pool of a canal, about 30 metres away from the village. It was overgrown with submerged vegetation. Copper sulfate was used to treat this pond in November 1962 and again in November 1963, but snails reappeared 2 months after the treatment on each occasion, perhaps due to the reintroduction of snails from the canal. The data from monthly observations from September 1962 to December 1964 are given in Table 5. Cercariae from crushed snails collected in October–November 1963 and October 1964 developed in rodents into *S. bovis* only. The peak of snail population occurred in June and October in 1963, but only in November in 1964. The transmission sites in this village are many, but probably the nearby Abjirob Canal is the most important one.

Qaleh Now Sardar pond. Around this village, a chain of borrow-pits was dug for mud to use in building houses. Periodic snail searches were carried out in these ponds and it was found that the dry state alternated with the wet state but the former predominated. Until June 1964, a large number of snails was collected in one pond. The numbers of snails collected during 3 consecutive months from June to August 1964 were 634, 798, and 550, and the numbers with cercarial infections were 9, 7 and 0, respectively. This habitat was dry in September and October and became wet again in early November. The numbers of snails collected in November and December were 20 and 3, respectively, but none of them was infected. The cercariae from crushed snails collected in June and July developed in rodents into *S. haematobium* only. The village had a population of 238 persons and 52% were infected with *S. haematobium*. The habitat was entirely dry during 1965 and part of 1966 and no live snails were found until the end of 1966.

Two field ponds. These 2 habitats were side-pools of canals. Pond A was over 1 km away from the village of Deylam Bakhakh and pond B was 500 metres away from the village of Farash Abad. The data from monthly observations from September 1962 to December 1964 are presented in Table 6. Snail densities in these 2 habitats were generally low and during several months, snails could not be collected. No outstanding peak populations appeared during the observation period; only a single infected snail was collected in each pond, in October 1964 in pond A and in March 1963 in pond B. Judging from the limited human contact with the habitats, it seems probable that schistosomes transmitted will be *S. bovis*.

Farash Abad Swamp. This was a large depression near the village, with *Typha* growing in it. The village had a population of 179 persons and 65% of them were infected with *S. haematobium*. The data from monthly observations from March 1963 to December 1964 are presented in Table 7.

TABLE 6

NUMBERS OF *B. TRUNCATUS* COLLECTED MONTHLY AND NUMBERS INFECTED WITH MAMMALIAN SCHISTOSOMES FROM TWO FIELD PONDS IN KHUZESTAN

Month	Pond A[a] (old Deylam Bakhakh) during year			Pond B[a] (near Farash Abad) during year		
	1962	1963	1964	1962	1963	1964
January		0/14	0/2		0/42	0/13
February		0	0		0/33	0/12
March		0	0		1/9	0/46
April		0/4	0		0/9	0/2
May		0	0		0/10	0/21
June		0/2	0		0/71	0
July		0	0		0/16	0
August		0	0/48		0/6	0
September	0/5	0	0/4	0/19	0/21	0
October	0	0	1/46	0/22	0/23	Dry
November	0/3	0/12	0/43	0/13	0/23	Dry
December	0/5	0/15	0	0/21	0/17	0

[a] Numerators = number of snails with mammalian schistosome infections; denominators = total number of snails collected.

Snails were first found in March 1963 and were collectable for the 4 following months in 1963. After a summer drought, no snails were found until the next April. Snails could also be collected for 4 months from April to July in 1964. After summer drought, no snails were found for the rest of the year. Peaks of snail population occurred in May 1963 and May 1964. The infected snails were found in April and May 1963; the cercariae from these infected snails developed in rodents into *S. bovis* only. Apparently, there are many transmission sites in this village; the canal passing through the village was infested with *B. truncatus* and might be one of the main transmission sites.

Bayatian Swamp. Around this village there were numerous snail habitats. The swamp received excess water from the field and scarce vegetation grew in it. The data from monthly observations from September 1962 to April 1964 are given in Table 7. The snail densities were always low and snails could not be collected for months; no infected snail was found during the observation period. Although 26% of the 161 people in this village were infected with *S. haematobium*, transmission might take place in other ponds or canals nearby.

TABLE 7

NUMBERS OF *B. TRUNCATUS* COLLECTED MONTHLY FROM 4 SWAMPS IN KHUZESTAN AND NUMBERS INFECTED WITH SCHISTOSOMES

Month	Farash Abad[a]		Bayatian[a]			Banutimoezi[a]			Shahur Stream[a]		
	1963	1964	1962	1963	1964	1962	1963	1964	1962	1963	1964
Jan.	—	0		0/2	0		0/14	0		0/10	0/3
Feb.	—	0		0/7	0		0/1	0		0/8	—
March	0/179	0		0/19	0/1		0/6	0		—	0
April	1/130	0/1		0/11	0		2/96	0		0/10	0
May	24/360	0/99		0/16			3/62	0/46		0/115	0
June	0/199	0/4		0/16			Chem.[b]	0/2		0/19	0/5
July	Dry	0/2		0/6			0	0/3		—	0
Aug.	0	Dry		0			0	0/2		—	0/3
Sept.	Dry	Dry	0	0			0	0	0/62	0	0
Oct.	0	0	0/155	Dry		2/20	0	0	0/5	—	0
Nov.	0	0	0/5	0		2/302	0	0/15	1/15	0/5	0
Dec.	0	0	0/5	0		0/72	0	0/5	0/10	0/9	0

[a] Numerators = number of snails with mammalian schistosome infections; denominators = total number of snails collected.
[b] Molluscicide was applied.

TABLE 8

MAMMALIAN SCHISTOSOME INFECTION RATES OF *B. TRUNCATUS* IN KHUZESTAN IN PERIOD FROM 1962 TO 1964

Month	1962		1963		1964		Total	
	No.[a]	%	No.[a]	%	No.[a]	%	No.[a]	%
Jan.			6/312	1.9	13/710	1.8	19/1 022	1.9
Feb.			14/863	1.6	1/555	0.2	15/1 418	1.1
March			47/742	6.3	0/639	0	47/1 381	3.4
April			10/719	1.4	5/1 489	0.3	15/2 208	0.7
May			41/1 088	3.8	60/4 380	1.4	101/5 468	1.8
June			20/3 574	0.6	15/1 282	1.2	35/4 856	0.7
July			6/3 377	0.2	7/1 739	0.4	13/5 116	0.3
Aug.			15/1 471	1.0	0/975	0	15/2 446	0.6
Sept.	0/154	0	5/495	1.0	0/140	0	5/789	0.6
Oct.	59/591	10.0	8/1 304	0.6	27/1 676	1.6	94/3 571	2.6
Nov.	24/1 584	1.5	9/741	1.2	20/9 866	0.2	53/12 191	0.4
Dec.	1/259	0.4	4/445	0.9	0/1 607	0	5/2 311	0.2

[a] Numerators = number of snails infected with schistosomes; denominators = total number of snails collected.

Banutimoezi Swamp. The habitat, which was 500 metres away from the village, had a central depression that remained wet throughout the dry seasons. The vegetation included *Potamogeton, Ceratophylum, Ranunculus* and other plants. The data from monthly observations from October 1962 to December 1964 are presented in Table 7. The infected snails were found in October–November 1962 and in April–May 1963. Cercariae from the crushed snails developed into *S. bovis* in rodents. An examination of 69 persons out of a population of 378 in this village revealed no schistosome infections. The results indicate that this swamp has served as a transmission site for *S. bovis* only.

Shahur Stream Pool. The stagnant branch of the Shahur Stream forms several isolated marshes during the dry season. The snail collection was made in a swamp located near the small village of Aiteh. *Typha* grew predominantly in the centre of the swamp and other plants grew round the edges. Water flowed in this habitat for only a short time during the rainy season, and in spite of this flow, the water moved sluggishly on the sites. The data from monthly observations from September 1962 to December 1964 are given in Table 7. The snail densities were generally low and snails could not be collected in some seasons. A single infected snail only was collected in November 1962. The village had a population of 60 persons, 59% of whom were infected with *S. haematobium*. Possibly this stretch of water is a transmission site for the village.

In summary, for the period from 1962 to 1964, the total number of snails and the number of snails harbouring mammalian schistosome cercariae are given in Table 8. The results show that the infection rates varied with the season and the year, and that the infection rate did not increase with the snail population. The number of habitats examined and the number that contained infected snails during the period from 1962 to 1964 are given in Table 9. The results indicate that transmission seasons occurred in spring and autumn and that transmission was mainly of *S. bovis*. The size frequency of snails harbouring mammalian schistosome cercariae in the period from 1963 to 1964 is given in Table 10 and the results of these measurements show that 64.6% of the infected snails were over 10 mm in length.

TABLE 9

MAMMALIAN SCHISTOSOME INFECTION RATES OF HABITATS IN KHUZESTAN DURING THE PERIOD 1962–64

Month	1962 [a]	1963 [a]	1964 [a]	Total No.[a]	Total %
January		2/8	1/9	3/17	17.6
February		2/8	1/9	3/17	17.6
March		2/8	0/11	2/19	10.5
April		4/8	2/11	6/19	31.6
May		4/9	2/10	6/19	31.6
June		1/8	2/9	3/17	17.6
July		1/8	1/9	2/17	11.8
August		1/8	0/9	1/17	5.9
September	0/6	2/9	0/9	2/24	8.3
October	3/7	2/8	4/9	9/24	37.5
November	6/9	2/9	1/9	9/27	33.5
December	2/8	1/8	0/9	3/25	12.0

[a] Numerators = number of habitats containing infected snails; denominators = number of habitats examined.

Natural schistosome infections and monthly population trends of B. truncatus *in running waters*

Two new irrigation canals in the sugar-cane area. The new irrigation system at the time of this study consisted of 9 reservoirs used as night storage dams, some 143 km of main canals, over 30 km of secondary canals, over 40 km of tertiary canals and hundreds of furrow-channels that provided good habitats for snails. Two secondary canals were chosen for the present study. The flow was interrupted during the winter months when less water was needed in the fields. In these canals, upstream flow was rapid but it slowed near the gate of a reservoir where the water moved sluggishly and plants grew. The number of snails collected monthly from January 1965 to May 1967 is given in Table 11. It was found that more snails were collected during cold months than during warm months. No schistosome-infected snails were collected.

TABLE 10

SIZE-FREQUENCY OF *B. TRUNCATUS* INFECTED WITH MAMMALIAN SCHISTOSOMES DURING THE PERIOD 1963-64

Year	Number of infected snails of size (mm) shown: 0–4	4–6	6–8	8–10	10–12	12–14	⩾14
1963	1	24	29	41	47	20	23
1964		1	6	16	64	52	9
Total	1	25	35	57	111	72	32

TABLE 11

NUMBERS OF *B. TRUNCATUS* COLLECTED [a] MONTHLY FROM 2 NEW IRRIGATION CANALS OF THE SUGAR-CANE AREA IN KHUZESTAN

Month	Canal 1			Canal 2		
	1965	1966	1967	1965	1966	1967
Jan.	Dry	68	26	Dry	3	307
Feb.	Dry	38	53	Dry	90	84
March	82	19	10	170	23	6
Apr.	2	0	7	37	20	5
May	0	2	10	9	0	3
June	12	1		0	1	
July	9	5		9	10	
Aug.	8	0		9	10	
Sep.	0	3		0	44	
Oct.	0	1		7	9	
Nov.	13	5		Dry	37	
Dec.	5	Dry		Dry	Dry	

[a] Per 30 nets.

Five irrigation canals in the Abjirob area. These earth canals received water from the main Abjirob Canal, which branched off from the Abjirob Stream above a dam built some 20 years ago. The flow of water in the canals was slower in winter than in summer. In summer, ricefields adjoining the canals used much of the water from the canals so that a minimum of water continued to run into the tertiary canals. The snail collections were made at 10 sites along each canal and 30 nets were passed at each site. The monthly number of snails as shown in Table 12 were collected from one site at the terminal end of 5 canals. The results showed that a snail population peak was built up in cold months in three of the canals but in the Seyed Nur and Boneh Hajat canals the snail

TABLE 12

NUMBERS OF SNAILS COLLECTED MONTHLY AND NUMBERS INFECTED WITH SCHISTOSOMES FROM 5 CANALS IN THE ABJIROB AREA OF KHUZESTAN

Month	Seyed Jafar [a]			Seyed Magid [a]		Boneh Ayesh [a]			Seyed Nur [a]		Boneh Hajat [a]	
	1965	1966	1967	1966	1967	1965	1966	1967	1966	1967	1966	1967
Jan.		0/85	0/366	0/32	0/6	0/100	—[b]	0/171	0/3	0/4	0	0
Feb.		0/291	0/16	0/5	0	Dry	0/196	0/13	0/23	0	0/1	0/2
Mar.		Deepened	0/17	0	0	0/20	0/93	0/25	0	0/2	0	0
Apr.		0/8	0/17	0/1	0	0	0/55	0/9	0	0/2	0	0/1
May		0	0/16	Chem.[c]	0	0/17	Chem.[c]	0/14	0/1	0/1	0	0
June		0		0/1		0	0		0/1		0	
July		0/5		0/6		0/4	0/2		0/16		0/43	
Aug.		0/5		0/2		0/2	0/7		0/4		0/18	
Sept.		0/30		2/6		0/5	0/11		0/17		Dry	
Oct.		0/39		0/6		0/6	0/44		0/3		0	
Nov.	7/23	0/44		0/11		0/39	0/46		0/17		0	
Dec.	—[b]	0/157		0/2		—[b]	—		—[b]		0	

[a] Numerators = number of snails infected with schistosomes; denominators = total number of snails collected.
[b] Not surveyed.
[c] Molluscicide applied.

densities were comparatively high in summer months. Infected snails were found only in 2 canals: in the Seyed Jafar Canal, 7 out of 23 snails collected in November 1965 were infected with *S. haematobium,* and in the Seyed Magid canal, 2 out of 6 snails collected in September 1966 were also infected with *S. haematobium*. The identifications of schistosomes were made by infecting rodents.

In general, the over-all prevalence of *S. haematobium* in this area was higher than in any other area in Khuzestan and the transmission sites were apparently canals since no other habitats existed near the villages.

Deylam Bakhakh Canal. This was a tertiary canal branching off from a Farash Abad canal. It was some 5 km long and contained several widened stretches where plants grew. During summer and autumn, the rice plantation in the area adjoining the middle stretch of the canal used most of the water from the canal and kept a minimum of water running in the remainder; thus, the water in the canal near the village was stagnant. In other seasons, owing to the lack of a dam in the watershed to regulate the flow of water, the flow was rapid throughout the course. The monthly numbers of snails and the numbers infected that were collected during the period from 1965 to 1966 are given in Table 13. It was found that snails could be collected in summer and autumn and infected snails were collected in October 1965 and in July 1966. Cercariae from snails collected in October 1965 developed into *S. haematobium* in rodents but those from snails collected in July 1966 developed into male worms only and the species could not be determined.

This village had a population of 200 persons and 79% were infected with *S. haematobium*. The canal has certainly served as an important focus of transmission for the village.

Deylam Sofla Canal. This was an old canal in the new irrigation project area. Snail searches were carried out in this canal during 1965; the first batch of snails was collected in June 1966. The numbers of snails collected in the following months together with the numbers infected are shown in Table 13; snails could be collected only in summer months. In August 1966, 6 out of 37

TABLE 13

NUMBERS OF SNAILS COLLECTED [a] MONTHLY AND NUMBERS INFECTED WITH SCHISTOSOMES FROM 2 OLD CANALS AND A FIELD-DRAIN IN KHUZESTAN

Month	Deylam Bakhakh canal		Boneh Mesban drain		Deylam Sofla canal (old)
	1965	1966	1964	1965	1966
Jan.	— [b]	0		0/39	0
Feb.	0	0		0/71	—
March	0	0	0/363		0
Apr.	0	0	0/963		—
May	0	0	0/1795		0
June	0	0/5	0/151		0/3
July	0	2/21	0/448		0/13
Aug.	0/2	0/17	0/1		6/37
Sept.	0/5	0/5	0/2		Dry
Oct.	5/18	0/9	1/26		Dry
Nov.	Chem. [c]	0/21	0/181		0
Dec.	0	0/5	0/69		0

[a] Numerators = numbers of snails infected with schistosomes; denominators = total number of snails collected.
[b] Not surveyed.
[c] Molluscicide applied.

snails were shown, by laboratory infection of rodents, to be infected with *S. haematobium*.

The village had a population of 450 persons, 73 % of whom were infected with *S. haematobium*. The canal served as one of the important transmission sites.

Boneh Mesban field-drain. This was a long, narrow field-drain with several *Typha* pools along its length. At low water levels, only the pools remained wet. Snail collections were made near the village from March 1964 to February 1965; the results are shown in Table 13. The major peak of snail population was found in May and there was a minor one in November. Only 1 infected snail was found; that was in October 1964. The village had a population of 33 persons and 53% of them were infected with *S. haematobium*. Evidently, this drain might be an important transmission site.

Shovayeh field-drain. This habitat was a long, narrow drain with several *Typha* pools along its length; water was collected from the field and emptied into the Shahur Stream. The first batch of snails was collected in November 1964 and it was possible to collect snails until May 1965. Thereafter, no live snails were found for the next 19 months. The reasons for the disappearance of the snails are unknown, but the snails might have been washed down by fast-flowing water in May–June which was followed by summer heat and low water levels. No infected snails were found; nevertheless 45% of a population of 273 persons were infected with *S. haematobium* in this village. As there were no other snail habitats near this village, this drain might be an important transmission site.

DISCUSSION

Gaud et al. (1962) reported the existence of 144 snail habitats in the study area during the period from 1959 to 1961, although a certain number of these habitats contained only dead shells of *B. truncatus*. Upon the arrival of the senior author at the Project Area, a snail survey was carried out in July–September 1962 in the known habitats and it was found that the number of snail colonies that could be detected was less than 20 during the season. The majority of snail colonies inhabitating swamps, drains, canals and ponds were of the discontinuous type; that is, the snails could be collected in one season but not in another. Dense populations in such colonies seldom persisted for more than a few months. Periods during which there was negligible propagation of the snails often persisted for many months, or even for more than a year, with the snail populations reaching such low densities that they were near to extinction or they could no longer be collected. Such colonies, if they were not eradicated, would usually reappear in the next optimal season.

Reasons for the discontinuity of snail population are many. According to Gaud et al. (1962), drought and flooding in habitats are 2 of the main factors in limiting a snail population. Flooding may wash out snails from some tertiary canals and drains. Gaud et al. (1962) noted that the dry seasons occurred in May–June, September–October and the winter months. Nevertheless, the effect of drought in these seasons is found not to be as severe as drought in summer; because of summer drought, collections could not be made from 3 colonies for 4, 10, and 18 months during this study. The studies concerning the adaptation of *B. truncatus* to drought have been presented elsewhere (Chu et al., 1967a, 1967b, 1967c, 1967d). Although the breeding activity of *B. truncatus* after desiccation was found to be intense in the laboratory and in the field, the time required for a desiccated colony to reach a collectable size after the return of water varies with the habitat and occurs sooner in a deep habitat than in a shallow habitat, possibly due to differences in food resources and fluctuations of the water level between the 2 kinds of habitats following a period of drought.

From observations on a limited number of snail habitats, as reported in this paper, *B. truncatus* is seen to breed throughout the year, which confirms the finding of Gaud et al. (1962). Fresh eggs were collected when the water temperatures were approaching freezing-point in the middle of January 1964; but intensive breeding activity may occur in any month from October to May.

A peak of snail population is usually preceded by intensive breeding 1 or 2 months previously, but this is not always true. It was found in some habitats that even when there were numbers of egg-masses, the snail population did not increase but in fact decreased during subsequent months. Such eggs were tested in the laboratory and found to be normal. The failure of a snail population to develop from these eggs might be the result of heavy mortality of prejuvenile snails which perhaps died due to scarcity of food or to some unknown factors.

The size of a snail population is apparently controlled by the physical, chemical and biological factors in a habitat. Temperature and hydrographic changes in a habitat on the one hand, and competition with other species of snails as well as the activities of natural predators such as *Chaetogaster* on the other hand, are among the important factors that exercise natural selection in a snail habitat.

In the early part of January 1964, when the field water temperatures dropped gradually from around 10°C to about freezing-point, freshly laid eggs were still collected daily. At water temperatures of 6°C–8°C, snails were observed to move actively on the bottom of a shallow habitat. However, eggs exposed to a range of water temperatures from 4°C to 8°C failed to develop (El-Gindy, 1965; and our unpublished data). It appears that the effect of cold on the hatchability of eggs is far more important than on breeding in areas with a long cold season. After the short period of freezing temperatures that occurred from 19 to 23 January 1964, the snail population was reduced greatly in shallow habitats but not in deep habitats; evidently, the snails in the deeper water might shelter on the bottom of the habitat where temperatures were still within the limits of tolerance.

In warm seasons when water temperatures rose to 35°C–38°C in the afternoons, the snail population in a habitat would fall considerably. In a shallow habitat, such unfavourable temperatures would arise earlier in the day, the duration of high temperatures would be longer, and fluctuations of water level would be more severe. Thus, a potential peak of snail population expected to appear in May–July in deep habitats would disappear unless the habitat was frequently supplied with fresh canal water. Judging from the size distribution of snails collected, it was found that summer was not a favourable time for snails to grow to a size greater than 10 mm in length although snails over this size were common in other seasons.

In a deep habitat at Najaf Abad, intensive breeding took place in February–March 1963, but the snail density was not found to increase in subsequent months until early July. Perhaps, in these months, an equilibrium between the biotic potential of snails and the environmental resistance had already been reached. Only when a warm optimum temperature prevailed in June was such an equilibrium altered. The warm temperature is not only favourable for the early hatching of eggs and optimal development of young snails, but also for maximal growth of the snails' food organisms, i.e., microflora.

In standing waters in this area, the potential peaks of snail population may occur in 2 periods, one in May–July and the other in November–January. In flowing waters, snail colonies are also of the discontinuous type but higher numbers of snails may be collected in cold months in one group of canals, and in summer months in another group of canals. The water of the former was sluggish in cold months, and of the latter in the summer months.

As the majority of habitats contain low densities of snails and as snail colonies are subject to the incessant processes of natural selection, the question will arise regarding a method for evaluating molluscicidal effort, if such a programme is to be used to prevent the spread of schistosomiasis in this area. Ordinarily, the efficacy of molluscicidal effort is measured by the degree of reduction of snail densities after treatment in comparison with densities before treatment at the same season, using a uniform sampling method. This method may work in a habitat where regular snail densities are high and annual variation in snail densities is low, or in some habitats, such as canals, where the introduction of new snails from upstream is regular. However, it seems to be of limited value in standing waters in this area. When the snail density is low, the present sampling methods often show a large error. According to Yeo (1962), failure to find any living snails in a habitat does not prove the complete absence of snails, or a complete kill after treatment with molluscicide, because there is 1 chance in 40 that the true count should be 3 or more. The same author further noted that, for the evaluation of very low population levels, there is no reliable method at present and he therefore recommended that sampling over extended periods rather than massive sampling in a short period should be used to decide whether eradication has been achieved because, if eradication has not been achieved, there will be a progressively increasing population and individual snails will more likely be found in the later samples.

The results of this study indicate that the yearly peak of snail population may occur twice or only once. Thus, for evaluating molluscicidal effects of treatments of standing waters in Iran, it is proposed that a presumptive " complete kill " of *B. truncatus* in a habitat after molluscicidal treatment should be the result of negative finding in monthly collection for a period of 1 year or longer, covering at least 2 potential snail population peaks. A " failure " may be counted when 1 or more live snails is collected within 1 year of treatment.

In standing waters, Gaud et al. (1962) carried out their studies in the same area in 1959–61 and found that the transmission of mammalian schistosomes, based on the numbers of infected *B. truncatus* collected from the field, practically stopped during the first 4 months of the year. On the contrary, the results of our study showed that the snail infection rates during the first 4 months of a year were quite high. In standing waters, the optimum transmission seasons of mammalian schistosomes are spring and autumn; a finding confirming the work conducted in the laboratory and in outdoor aquaria (Chu et al., 1966a, 1966b). In flowing water, transmission is closely related to intensity of man–water contact, and may take place in hot months. This observation is substantiated by our finding that infected snails were collected in canals from May to November.

With regard to the location of snail habitats in relation to transmission, it is believed that swamps and some field ponds, far away from the village, may serve only as transmission sites for *S. bovis*. The results of the present study indicate that village ponds also play an important role in transmission of bovine schistosomiasis. Judging from our finding that snails infected with *S. haematobium* were recovered from only 2 village ponds but from 4 canals, canals might seem to play a more important role in transmission of urinary schistosomiasis than do other types of habitats.

The relation between snail habitats and transmission of urinary schistosomiasis requires further elucidation. Bodies of water of 2 types are found in the area in the close vicinity of a village; they are ponds and canals. Gaud et al. (1962) noted that canals might be places of human contamination but not snail habitats. On the contrary, we found that canals are snail habitats and as such play a role in the transmission of urinary schistosomiasis. This observation is further substantiated by the epidemiological picture of this area as discussed below.

In the study area, excluding some villages below the sugar-cane area, there are 188 villages, mostly 5 km–10 km apart. A total of 40 villages have a prevalence rate for schistosomiasis of over 21% (F. Arfaa, unpublished data); it is admitted that the main transmission occurs locally. Except for 16 villages from which the transmission sites disappeared for some time or are unknown, there remain 24 villages which can be used to determine the transmission patterns in this area. Based upon the type of snail habitats located near a village, 3 groups of villages can be recognized (Table 14):

Group 1; 11 villages with snail-infested ponds (borrow-pits) only.

TABLE 14
RELATION OF SNAIL HABITATS AND INFECTION RATES OF SCHISTOSOMIASIS IN VILLAGES IN KHUZESTAN

Group [a]	Village	Population	No. of people examined	Schistosomiasis positive	
				No.	%
1	1. Qaleh Sheikh	165	131	4	3.1
	2. Balengun	177	62	5	8.1
	3. Bonvar Hossein	242	99	1	1.0
	4. Abde Mohamad	127	112	1	0.9
	5. Najaf Abad	564	510	4	0.8
	6. Selar Abad	476	210	11	5.2
	7. Qaleh Gotb	1 224	111	0	0
	8. Chegha-Sorkh	232	222	3	1.4
	9. Qaleh Seyed	259	231	10	4.3
	10. Shahabad	667	641	217	33.9
	11. Qaleh Now Sardar	238	238	124	52.1
2	1. Boneh Alvan	277	115	45	39.1
	2. Boneh Khepel	65	12	4	33.3
	3. Sarda Abad	303	62	27	43.5
	4. Boneh Yakub	125	112	37	33.0
	5. Seyed Nur	286	88	29	33.0
	6. Boneh Ayesh	110	44	30	68.2
	7. Seyed Jafar	220	58	14	24.1
	8. Boneh Javaz	110	51	37	72.5
	9. Deylam Bakhakh	200	188	149	79.3
	10. Shongor Olia	213	184	88	47.8
	11. Shovayeh [b]	273	73	33	45.2
	12. Boneh Hati	61	29	7	24.1
	13. Boneh Mesban [b]	33	15	8	53.3
	14. Deylam Olia	320	302	107	35.4
3	1. Shongor Sofla	153	144	77	53.5
	2. Farash Abad	179	165	106	64.2
	3. Qaleh Abad Shah	695	638	172	27.0
	4. Naser Mousa	119	41	27	65.9
	5. Boneh Lazem	138	49	11	22.4
	6. Shamoun	477	295	135	45.8
	7. Deylam Sofla	450	217	160	73.7
	8. Bayatian	433	161	42	26.1

[a] 1 = villages with snail-infested ponds only nearby; 2 = villages with snail-infested canals only nearby; 3 = villages with snail-infested ponds and canals only nearby.
[b] With a snail-infested field-drain which functions also as a canal.

Group 2; 15 villages with snail-infested canals only.

Group 3; 8 villages with both snail-infested ponds and canals.

Statistical analysis showed that differences in transmission between group 1 and group 2 and between group 1 and group 3 are significant, but that the difference between group 2 and group 3 is not significant. It is reasonable to conclude that canals have been more important than borrow-pits or ponds in the transmission of human schistosomiasis in the area. However, as snail populations in running waters and stagnant waters are largely discontinuous, transmission patterns are more likely to be sporadic than stable in seasons or in years. As is often the case, when a new infection is detected in a village, the transmission may have been in post-peak stage.

In 9 out of the 11 villages in group 1, there are active snail habitats near the village but transmission of urinary schistosomiasis is minimal or absent. There may be many reasons for this, such as less frequent and shorter-lasting man–water contacts in the snail habitats, zooprophylaxis due to immunization caused by *S. bovis* (Nelson et al., 1962; Li Hsu et al., 1966) or by *Ornithobilharzia turkestanicum*, either or both of which are prevalent in snail habitats, or the low prevalence of schistosomiasis in the particular village. In such villages, people prefer to use water from canals near their homes which are not snail-infested and which are fast-flowing, thus minimizing the chance of the disease being transmitted.

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RÉSUMÉ

De 1962 à 1967, des investigations ont été menées au Khuzestan, dans le sud-ouest de l'Iran, sur la répartition et l'écologie de *Bulinus truncatus*, hôte intermédiaire de *Schistosoma haematobium* et de *S. bovis*.

Des mollusques vivants ont été découverts dans quatre foyers: au centre de la région étudiée (foyer principal), sur le cours inférieur du Karkheh, sur le cours supérieur du Karun et dans le bassin du Bala Rud. Des spécimens morts ont été trouvés en trois autres endroits. Dans la plupart des cas, les mollusques peuplaient des marécages, des rigoles d'écoulement, des canaux et des étangs; leur nombre était peu élevé et leur distribution très inégale.

On s'est efforcé de déceler une corrélation entre la composition chimique des eaux naturelles et la répartition en foyers épars des populations de *B. truncatus*. En étudiant l'influence de la salinité au laboratoire, on a constaté que la présence dans l'eau de chlorure de sodium à la concentration d'environ 1300 parties par million est compatible avec un développement des mollusques en nombre limité; lorsque la teneur en sel dépasse 2000 parties par million, le cycle de vie du vecteur peut être interrompu. Dans les conditions naturelles, la salinité totale dans les marécages situés dans les régions les moins irriguées subit de fortes variations qui peuvent aller de 1000 environ à plus de 2000 parties par million. Ce facteur limitant, aggravé par les effets de la dessiccation, est le principal responsable des fluctuations du nombre des mollusques observées selon les endroits. Dans les régions bien irriguées, la répartition des populations du vecteur est plus uniforme. Dans les territoires qui ne bénéficient d'aucun système d'irrigation, la teneur des eaux de surface en solides dissous est si élevée que *B. truncatus* ne peut survivre.

On a d'autre part étudié la dynamique des populations de *B. truncatus* dans 32 habitats variés et sa signification en ce qui concerne la transmission de *S. haematobium* et *S. bovis*. Les évaluations mensuelles du nombre des mollusques montrent que ces derniers peuvent se reproduire de manière intensive entre octobre et mai. Dans les eaux stagnantes, un accroissement important des populations est virtuellement possible de mai à juillet et de novembre à janvier. Le printemps et l'automne sont les saisons les plus favorables à la transmission des schistosomes de mammifères. En eaux courantes, l'importance des populations de mollusques varie suivant la rapidité du courant et la température extérieure. La transmission est maximale durant les mois chauds.

Les étangs situés dans les villages jouent un rôle important dans la propagation de la schistosomiase bovine, alors que l'infection humaine à *S. haematobium* sévit surtout dans les régions où des canaux ont été aménagés. Ce fait est démontré par l'analyse des taux de prévalence de la schistosomiase urinaire dans les villages.

REFERENCES

Bijan, H. et al. (1962) *Urinary bilharziasis in Khuzestan and Pilot Programs for finding the best methods of prevention and control.* In: *Proceedings of the 11th Medical Congress of Iran-Ramzar*, pp. 198-207

Boycott, A. E. (1936) *J. Anim. Ecol.*, **5**, 116

Chu, K. Y. (1966a) *Bull. Wld Hlth Org.*, **34**, 131

Chu, K. Y. et al. (1966b) *Bull. Wld Hlth Org.*, **34**, 135

Chu, K. Y. et al. (1967a) *Ann. trop. Med. Parasit.*, **61**, 1

Chu, K. Y. et al. (1967b) *Ann. trop. Med. Parasit.*, **61**, 6

Chu, K. Y. et al. (1967c) *Ann. trop. Med. Parasit.*, **61**, 134

Chu, K. Y. et al. (1967d) *Ann. trop. Med. Parasit.*, **61**, 139

Deschiens, R. (1954) *Bull. Soc. Path. exot.*, **47**, 915

El-Gindy, M. S. & Radhawy, I. A. (1965) *Bull. endem. Dis.*, **7**, 13

Frank, G. H. (1963) *Bull. Wld Hlth Org.*, **29**, 531

Gaud, J., Arfaa, F. & Zeini, A. (1962) *Ann. Parasit. hum. comp.* **32**, 232

Gremliza, F. G. (1959) *Report on the operation of a mobile medical field unit and on a public health survey in the Dasht-Mishan area of the Khuzestan Region: December 1958 to June 1959*, Plan Organization of Iran

Harry, H. W. & Aldrich, D. V. (1958) *Bull. Wld Hlth Org.*, **18**, 819

Li Hsu, S. Y. et al. (1966) *Z. Tropenmed. Parasit.*, **17**, 407

Malek, E. A. (1958) *Bull. Wld Hlth Org.*, **18**, 785

Nelson, G. S., Teesdale, C. & Highton, R. B. (1962) *The role of animals as reservoirs of bilharziasis in Africa.* In: Wolstenholme, G. E. W. & O'Connor, M., ed., *Bilharziasis*, London, Churchill, p. 127

Olivier, L. & Schneidermann, M. (1956) *Exp. Parasit.*, **5**, 109

Saliternik, Z. & Witenberg, G. (1959) *Bull. Wld Hlth Org.*, **21**, 161

Schutte, C. H. J., & Frank, G. H. (1964) *Bull. Wld Hlth Org.*, **30**, 389

Watson, J. M. (1953) *Trans. roy. Soc. trop. Med. Hyg.*, **47**, 49

Watson, J. M. (1958) *Bull. Wld Hlth Org.*, **18**, 833

WHO Study Group on the Ecology of Intermediate Snail Hosts of Bilharziasis (1957) *Wld Hlth Org. techn. Rep. Ser.*, **120**

Yeo, D. (1962) *Bull. Wld Hlth Org.*, **27**, 183